

Physics Notes 10

KHYBER PUKHTOONKHWA TEXTBOOK



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FORWORD

It is fortunate that I am inspired by my students to provide this physics guide. I often experience that my students want me to write my own notes when I emphasize on sentence structures of definitions, statements, etc., when I list the points on board during my lecture. For example, a capacitor can be defined as 'it is a device that is used for storing electrical energy' because other devices such as batteries, inductors also store electrical energy. But the definition 'a device that stores electrical energy is called capacitor' may be wrong, because here all the devices that store electrical energy are termed as capacitors. In this guide I have tried my best on quality writing. However, there may be some typing mistakes, so I request that if you find any mistake, do not hesitate to contact me.

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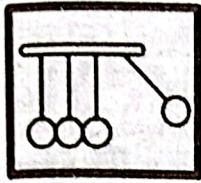
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Kishwar Khan

To my loved sons

Asad Khan, Asif Khan & Asim Khan

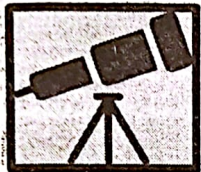
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**Simple Harmonic Motion
and Waves**



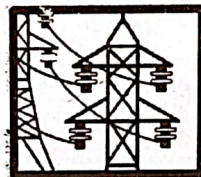
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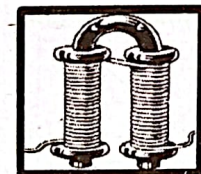
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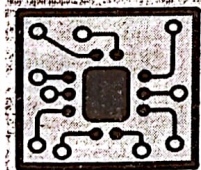
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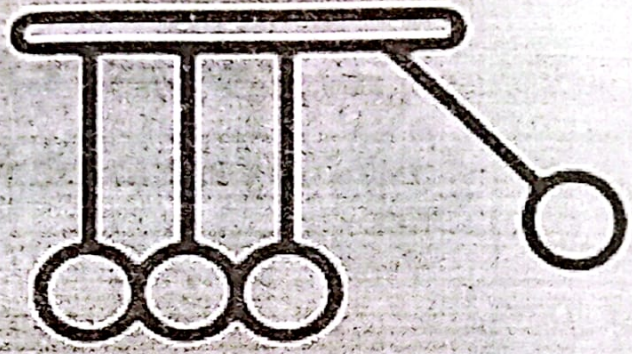
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UNIT 10

**SIMPLE
HARMONIC
MOTION
AND
WAVES**

Oscillatory Motion

The back and forth motion about equilibrium point is called oscillatory motion.

Terms Related to Oscillatory Motion

1. Oscillator

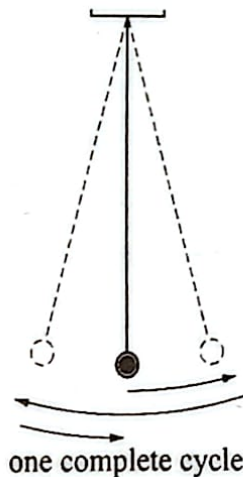
A system that executes harmonic motion is called oscillator.

2. Cycle / Vibration

One complete round trip of a vibrating body about the equilibrium position is called cycle or vibration.

3. Time period (T)

The time required to complete one cycle is called time period.



4. Frequency (f)

The number of cycles that a vibrating particle completes per unit time is called frequency.

The unit of frequency is *cycles per second* or *hertz (Hz)*

5. Relation between time period and frequency

Time period and frequency are reciprocal of each other.

i.e.

$$T = \frac{1}{f}$$

6. Displacement (x)

The distance of the oscillating body from the mean position at any instant of time is called displacement.

7. Amplitude (x_0)

The maximum displacement of a vibrating body from the mean position is called amplitude.



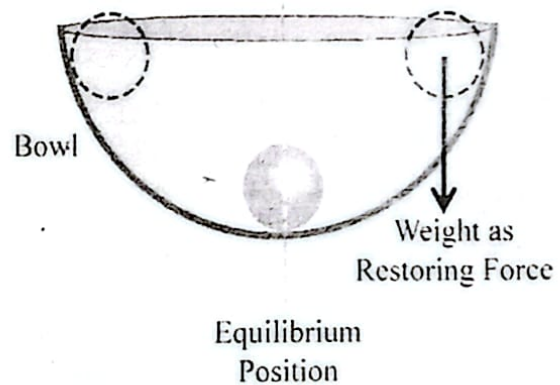
Simple Harmonic Motion (S.H.M)

Simple Harmonic Motion is a special type of oscillatory motion in which the acceleration of the vibrating body is directly proportional to the displacement and is always directed towards the mean position.

i.e. $a \propto -x$

Explanation

Consider a bowl and ball example as shown in the figure.



When the ball is displaced from its equilibrium position and released, it starts motion towards the equilibrium position under the action of restoring force. After reaching the equilibrium position the object continues its motion due to inertia and reaches the other extreme position. Thus the ball continues its back and forth motion about the equilibrium position.

S.H.M. is a special type of oscillatory motion where the restoring force is directly proportional to the displacement from the mean position.

i.e. $F_{res} \propto -x \dots\dots\dots(1)$

The negative sign shows that F_{res} is directed towards the mean position opposite to the displacement x .

S.H.M. is also defined in terms of acceleration. It is the type of oscillatory motion in which acceleration is directly proportional to the displacement and is directed towards the mean position.

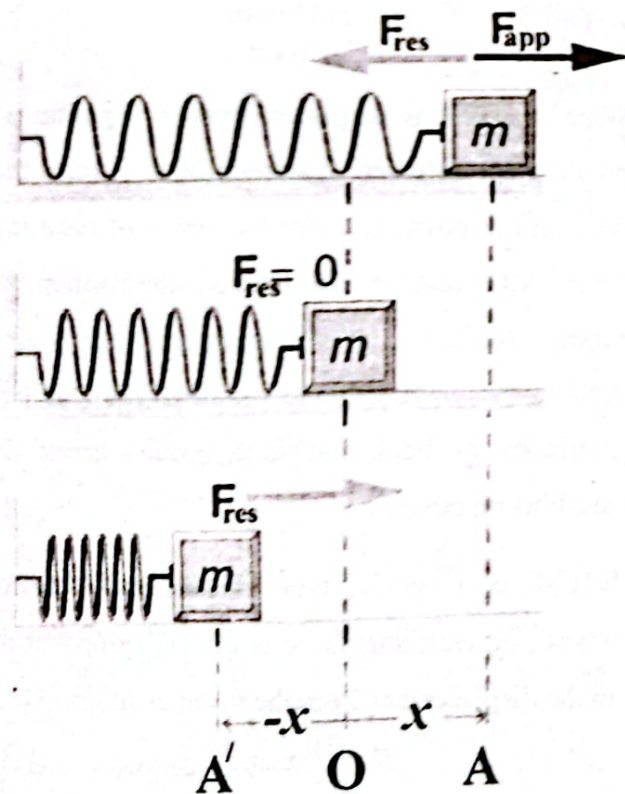
i.e. $a \propto -x$ (2)

We can say that equations (1) and (2) are the conditions for S.H.M.



Motion of Mass Attached to a Spring

Consider a block of mass ' m ' attached to one end of a spring and placed on a horizontal frictionless surface as shown in the figure.



When the block is displaced from its mean position and released it vibrates back and forth under the action of elastic restoring force.

According to Hook's Law the elastic restoring force ' F_{res} ' is directly proportional to the displacement ' x ' from the mean position.

i.e. $F_{res} \propto -x$

$\Rightarrow F_{res} = -kx$ (1)

Where ' k ' is the constant of proportionality called spring constant (force constant) and the negative sign shows that the restoring force and displacement are in opposite direction.

According to Newton's second law of motion

$F_{res} = ma$ (2)

Comparing equations (1) and (2), we get

$ma = -kx$

$\Rightarrow a = -\frac{k}{m}x$ (3)

As spring constant and mass do not change during the motion, so equation (3) can be written as

$a = -(\text{constant})x$

$\Rightarrow \boxed{a \propto -x}$ (4)

Equation (4) Shows that the oscillatory motion of mass attached to spring is S.H.M.

Time Period 'T' and frequency 'f' of mass spring system

Since acceleration in S.H.M. is

$a = -(\text{constant})x$ (A)

Where $\text{constant} = \frac{4\pi^2}{T^2}$

So equation (A) can be written as

$$a = -\frac{4\pi^2}{T^2}x \quad \text{.....(B)}$$

But, in case of mass-spring system;

$$a = -\frac{k}{m}x \quad \text{.....(C)}$$

Comparing equations (B) and (C), we get

$$-\frac{k}{m}x = -\frac{4\pi^2}{T^2}x \Rightarrow \cancel{x} \frac{k}{m} = \cancel{x} \frac{4\pi^2}{T^2}$$

$$\Rightarrow \frac{k}{m} = \frac{4\pi^2}{T^2} \Rightarrow T^2 = 4\pi^2 \frac{m}{k}$$

$$\Rightarrow \boxed{T = 2\pi \sqrt{\frac{m}{k}}}$$

Where 'm' is the mass of the block and 'k' is the spring constant or force constant.

Since frequency is the reciprocal of time period, so

$$f = \frac{1}{T} = \frac{1}{2\pi \sqrt{\frac{m}{k}}}$$

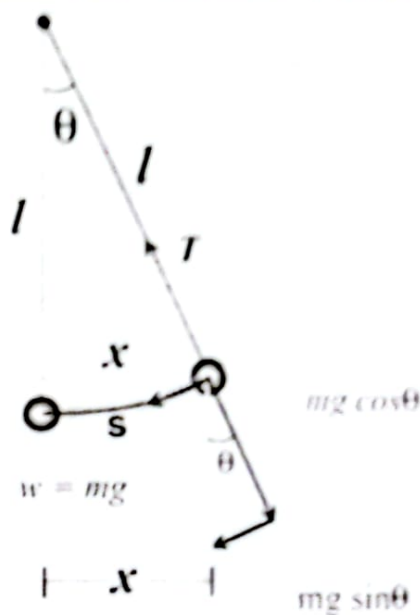
$$\Rightarrow \boxed{f = \frac{1}{2\pi} \sqrt{\frac{k}{m}}}$$



Simple Pendulum

A simple pendulum is an apparatus consisting of a bob suspended by a weightless and inextensible string supported from a fixed support so that it can swing freely under the influence of gravity.

We have to show that the motion of a simple pendulum is S.H.M. For this purpose resolve the weight of the bob into its rectangular components as shown in the figure.



The component ' $mg \cos \theta$ ' is balanced by the tension ' T ' in the string while the restoring force is provided by the component ' $mg \sin \theta$ '.

$$\text{i.e. } F_{\text{rest}} = -mg \sin \theta$$

$$\Rightarrow \cancel{m}a = -\cancel{m}g \sin \theta \quad (\because F_{\text{rest}} = ma)$$

$$\Rightarrow a = -g \sin \theta \quad \text{.....(1)}$$

The negative sign shows that the restoring force is directed so as to reduce the angle ' θ '.

In the figure if $\theta \ll 1$ then $s \approx x$. Therefore, from the figure

$$\sin \theta = \frac{x}{l} \quad \text{.....(2)}$$

Putting equation (2) in equation (1), we get

$$a = -g \frac{x}{l}$$

$$\Rightarrow a = -\frac{g}{l}x \quad \text{.....(3)}$$

As 'g' and 'l' are constants so equation (3) can be written as

$$a = -(\text{constant})x$$

$$\Rightarrow \boxed{a \propto -x} \quad \text{.....(4)}$$

Equation (4) Shows that the oscillatory motion of simple pendulum is S.H.M.

Time Period 'T' and frequency 'f' of**Simple Pendulum**

Since acceleration in S.H.M. is

$$a = -(\text{constant})x \dots\dots\dots (A)$$

Where $\text{constant} = \frac{4\pi^2}{T^2}$

So equation (A) can be written as

$$a = -\frac{4\pi^2}{T^2}x \dots\dots\dots (B)$$

But, in case of simple pendulum

$$a = -\frac{g}{l}x \dots\dots\dots (C)$$

Comparing equations (B) and (C), we get

$$-\frac{g}{l}x = -\frac{4\pi^2}{T^2}x \Rightarrow \cancel{\frac{g}{l}}x = \cancel{\frac{4\pi^2}{T^2}}x$$

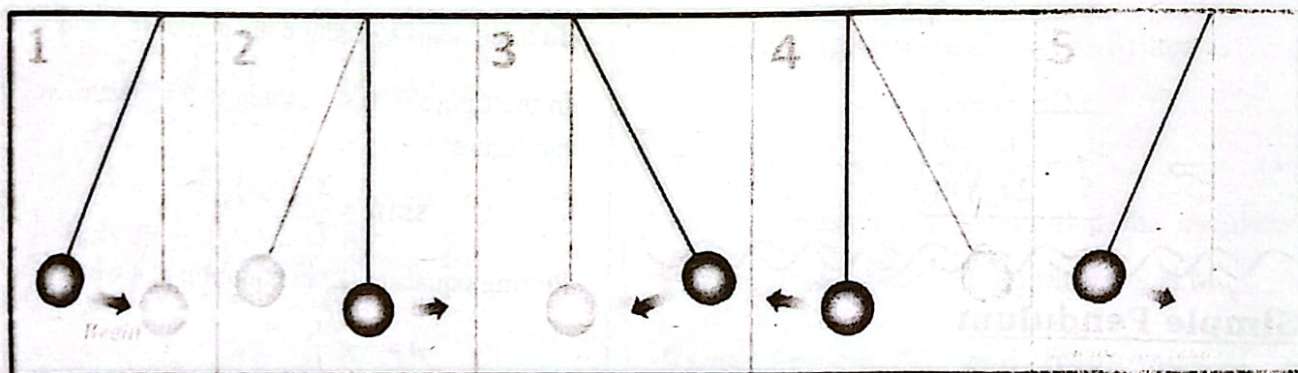
$$\Rightarrow T = 2\pi \sqrt{\frac{l}{g}}$$

Where 'm' is the mass of the block and 'k' is the spring constant or force constant.

Since frequency is the reciprocal of time period, so

$$f = \frac{1}{T} = \frac{1}{2\pi \sqrt{\frac{l}{g}}}$$

$$\Rightarrow f = \frac{1}{2\pi} \sqrt{\frac{g}{l}}$$

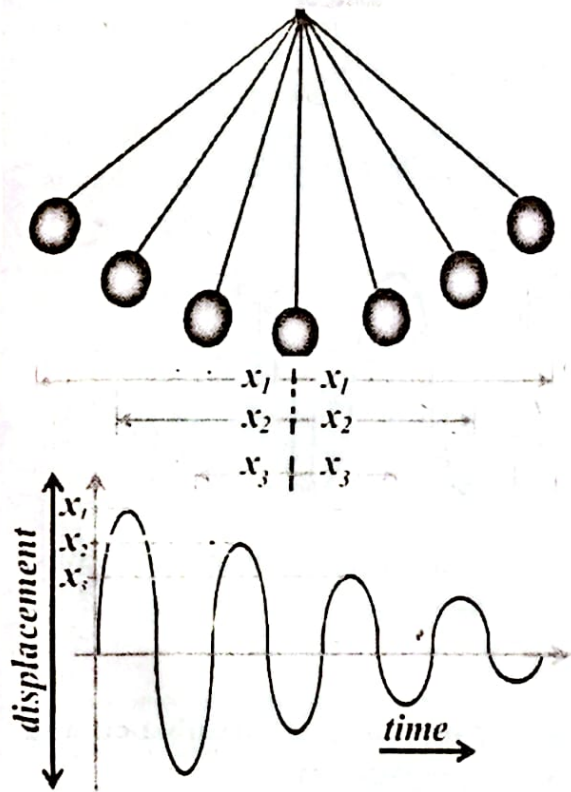
**C O N C E P T**

1. The restoring force pulls the pendulum towards the center (Equilibrium position).
2. The pendulum overshoots the equilibrium position because of its inertia.
3. The restoring force pulls back the bob towards the equilibrium position; slowing and reversing the pendulum's direction.
4. The pendulum overshoots the center again, because of its inertia.
5. The cycle repeats, creating harmonic motion.

Damping

The gradual loss of amplitude of an oscillator is known as damping.

When we swing pendulum it can be observed that the amplitude slowly decreases until the pendulum hang motionless.



Damping is due to friction which drains the energy away from motion and slows the oscillator down.



Waves

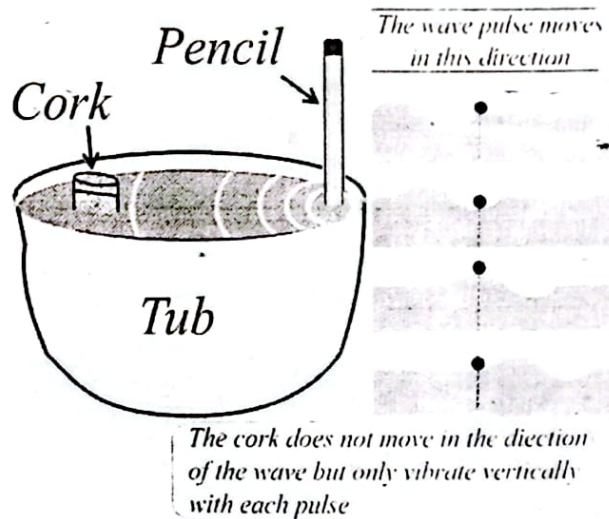
A wave is a disturbance that moves outward from its point of origin and transfers energy by means of vibrations of the particles of the medium.

The two common features of all waves are:

1. A wave is a travelling disturbance
2. A wave carries energy from one place to another place.

Explanation

When the disturbance moves through the medium, the matter does not move with it. Instead, each particle of the medium vibrates about the rest position as shown in the figure.



For example, waves are produced in the water by moving a pencil up and down at one edge of the tub. The waves move away from the point of origin and pass through the cork. We can observe that the cork starts moving up and down with the waves and does not move forward. The motion of the cork is due to the fact that the energy spent in moving the pencil reaches the cork by means of water wave.

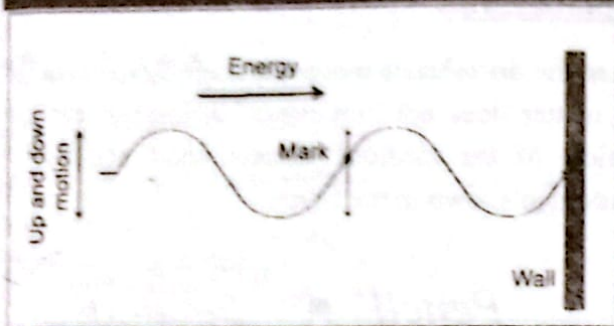
From this activity it is concluded that waves carry energy from one point in a medium to another point and particles of the medium (water) do not move forward with the wave but only vibrate about their mean position.



Examples of Waves

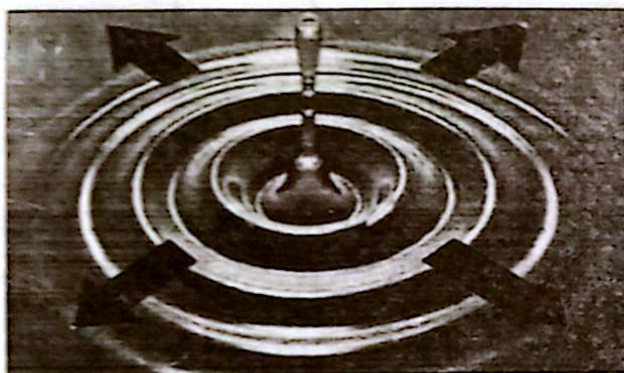
String waves

Take a rope and make a mark on it. Attach one end of the rope to a wall and wiggle the other end regularly. A snake-like motion is observed in the string as shown in the figure.



This snake-like motion is a wave-train consisting of a number of waves. It is noticed that the mark executes oscillatory motion about the mean position.

Ripples



When a stone is dropped into a pond of still water, ripples (waves) are produced on the surface of water. The particles at the point of impact absorb energy and start vibration. These particles transfer some of the energy to the neighboring particles which also start vibrating. In this way energy is spread out throughout the whole water.



Types of waves

In terms of elements (particles or fields) comprising the wave

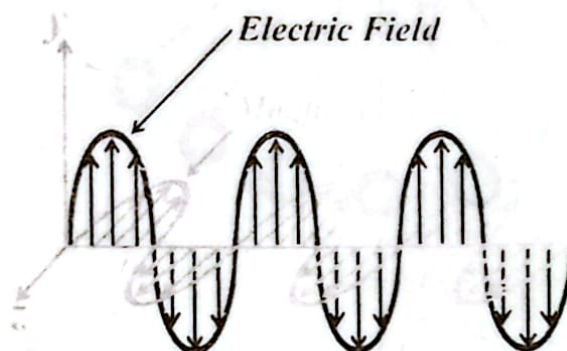
1. Mechanical waves

The waves that are propagated by the oscillation of material particles are called mechanical waves. These waves must require material medium for their propagation.

e.g. water waves, string waves, sound waves, seismic waves, etc.

2. Electromagnetic waves

The waves that are propagated by oscillation of electric and magnetic fields are called electromagnetic waves. These waves do not require material medium for their propagation. They are comprised of mutually perpendicular electric and magnetic fields.



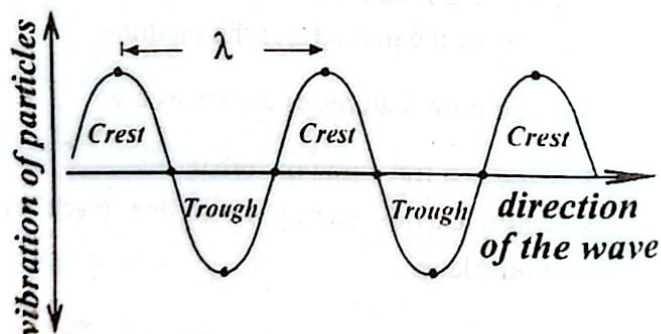
e.g. visible light, ultraviolet light, radiowaves, microwaves, X-rays, etc.

In terms of direction of disturbance and direction of propagation

1. Transverse Waves

Those waves in which the disturbance occurs perpendicular to the direction of propagation of the wave are called transverse waves.

e.g. water waves, string waves, all electromagnetic (EM) waves such as radiowaves, microwaves, visible light, IR, UV, X-rays, etc.



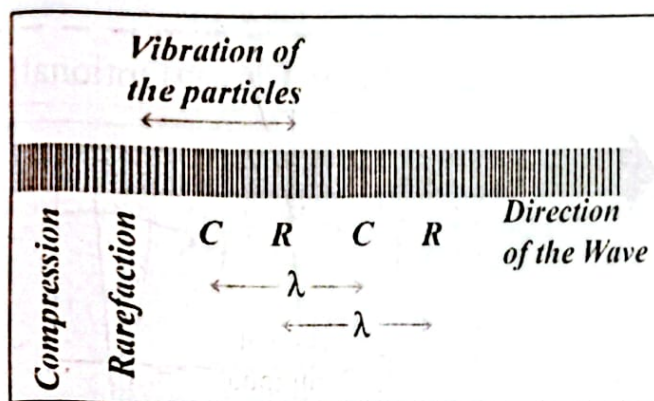
Crest: The part of the wave above the equilibrium position is called crest.

Trough: The part of the wave below the equilibrium position is called trough.

Wavelength of the transvers waves: The distance between two consecutive crests or troughs is called wavelength. Wavelength is denoted by ' λ ' and its SI unit is meter.

2. Longitudinal Waves

Those waves in which the disturbance occurs parallel to the direction of propagation of the wave are called longitudinal (or compressional) waves. e.g. sound waves etc.



Compression: The part of the wave that has higher density and pressure as compared to equilibrium density and pressure is called compression.

Rarefaction: The part of the wave that have lower density and pressure as compared to equilibrium density and pressure is called rarefaction.

Wavelength of Longitudinal waves: The distance between two consecutive compressions or rarefactions is called wavelength of the longitudinal waves.



Characteristic Wave Parameters

1. Wavelength λ

The shortest distance between two consecutive points which are in the same state of vibration is called wavelength.

The SI unit of wavelength is meter and is denoted by ' λ '.

2. Amplitude

The maximum displacement of the elements (particles or fields) of the wave from their equilibrium position as the wave passes through them is called amplitude of the wave.

The SI unit of amplitude is meter and is denoted by ' x_0 '.

3. Wave Cycle

The cycle completed by a point when a complete wave passes through it is called wave cycle. Wave cycle is denoted by 'N'.

4. Frequency

The number of wave cycles 'N' passing through a certain point per unit time is called frequency.

$$\text{i.e. } f = \frac{N}{t}$$

5. Time Period

The time required for one wave cycle to pass through a certain point is called time period of the wave.

Time period is the reciprocal of frequency.

$$\text{i.e. } T = \frac{1}{f}$$

The SI unit of time period is second and is denoted by 'T'.

6. Wave Speed

The distance travelled by a wave per unit time is called wave speed.

7. Relationship between speed, frequency and wavelength of a wave

As we know that

$$v = \frac{\Delta S}{\Delta t} \dots \dots \dots (1)$$

The wave travels a distance equal to its wavelength in time equal to its time period. i.e.

$$\text{if } \Delta S = \lambda \text{ then } \Delta t = T$$

So equation (1) can be written as

$$v = \frac{\lambda}{T}$$

$$\Rightarrow v = \lambda \times \frac{1}{T}$$

$$\Rightarrow v = \lambda f \quad (\because f = \frac{1}{T})$$

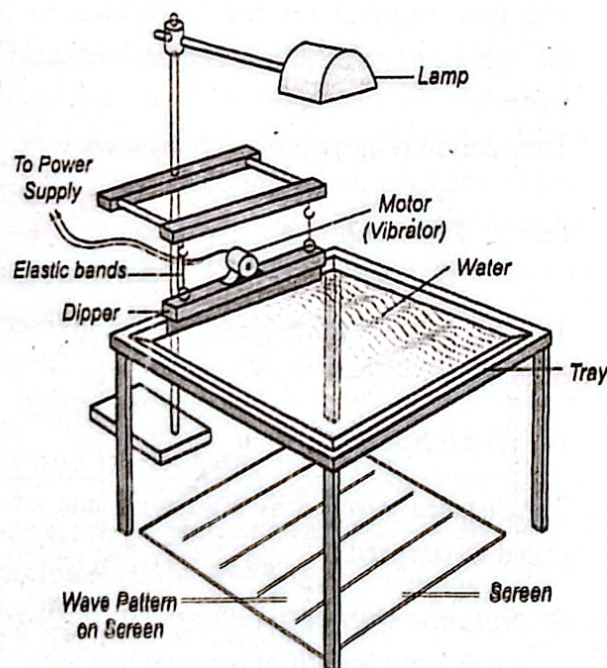
$$\Rightarrow \boxed{v = f\lambda \dots\dots\dots(2)}$$

Equation (2) is called universal wave equation because it applies to all waves.



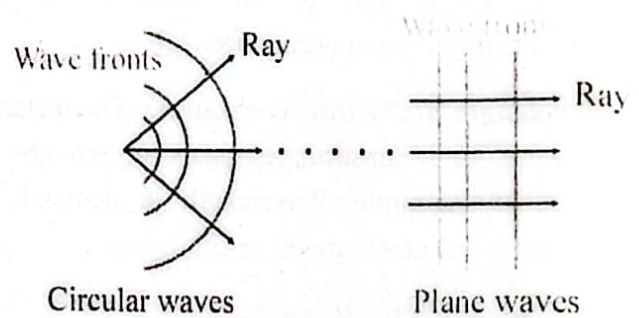
Properties of Waves

The basic properties of waves such as reflection, refraction, diffraction, etc. can be demonstrated by an apparatus called *Ripple tank*, as shown below.

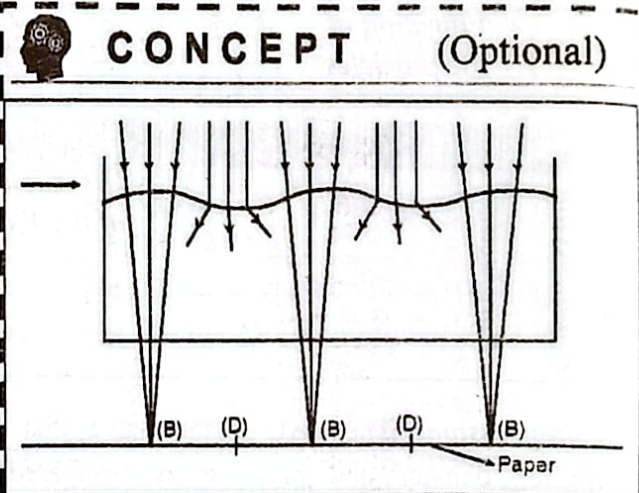


Wave front: Wave front comprises of all the points forming the crest of the wave. In short, wave front is another term for the crest of the wave.

Ray: A ray is a line drawn in the direction of wave motion, perpendicular to the wave front.



As shown in the figure, wave fronts far from the source have almost lost the curvature and are nearly straight. The straight wave fronts comprise plane waves.



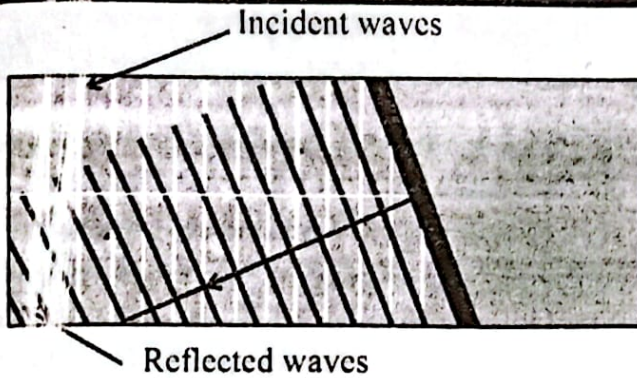
The **Bright** and **Dark lines** are formed on the screen (paper).

- The Bright lines are due to crests of the waves formed on the surface of water because crest acts as convex lens and converges the light rays.
- The Dark lines are due to troughs of the waves because trough acts as concave lens and diverges the light rays.

Reflection

The bouncing back of a wave front from a surface is called reflection. The reflected wave front returns into the same medium.

In the ripple tank reflection can be demonstrated by placing an upright barrier in the tray.



Refraction

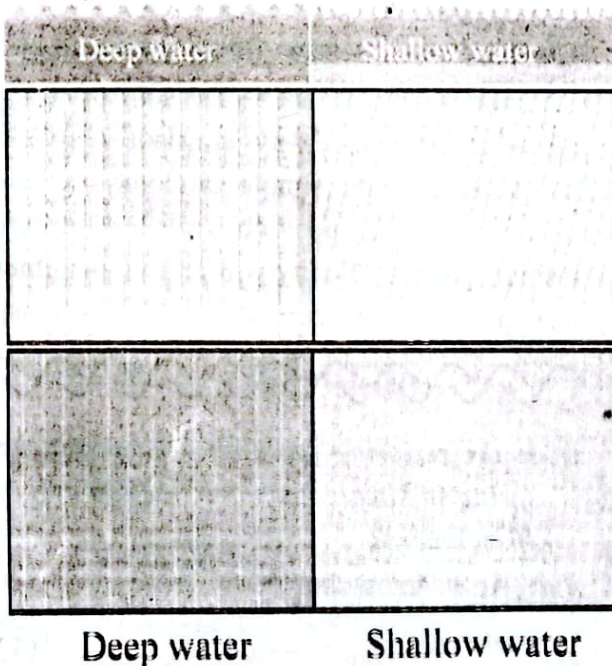
When waves travel from one medium into another medium, their speed as well as direction changes. This phenomenon is called refraction.

In ripple tank the refraction can be demonstrated by placing a thick sheet of plastic or glass in the way. When the waves travel from deep water to shallow water their direction as well as speed changes. It is observed that the wavelength increases. It is according to the universal wave equation;

$$v = f\lambda \quad (\because f = \text{constant})$$

$$\Rightarrow \boxed{v \propto \lambda}$$

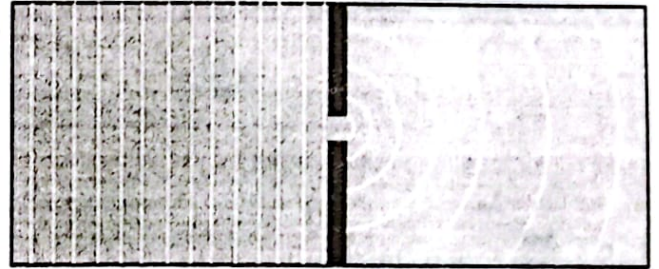
As the speed increases, the wavelength also increases and vice versa.



Diffraction

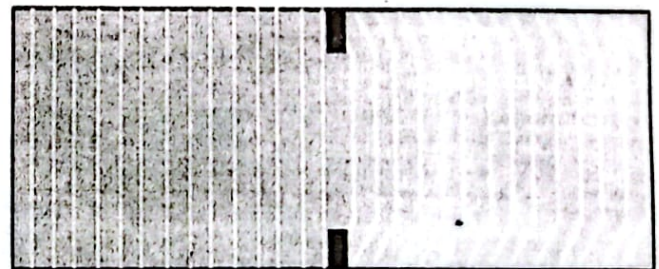
The bending of waves around the edges of an obstacle is called diffraction.

In ripple tank the diffraction can be demonstrated by placing two obstacles in such a way that the separation is comparable to the wavelength.



After passing the opening, waves spread out in all direction and change into circular waves.

If the separation is large as compared to the wavelength, the central part of the wave front is not affected and the diffraction occurs only at the edges of the obstacles.



EXERCISE**Multiple Choice Questions**

1	A transverse wave on a string has an amplitude A . A tiny spot on the string is colored red. As one cycle of the wave passes by, what is the total distance travelled by the red spot?			
	A	A	B	$2A$
	C	$1/2 A$		$4A$
2	Which of the following does not affect the period of the mass-spring system?			
	A	Mass	B	Spring constant
		Amplitude of vibration	D	All of the above affect the period
3	An object of mass ' m ' oscillates on the end of a spring. To double the period, replace the object with one of mass:			
	A	$2m$	B	$m/2$
		$4m$	D	$m/4$
4	A car mounted on shock absorbers is like a mass on spring. If we ignore damping, how will the frequency of the oscillations change if passengers (or a heavy load) are added to the car? The frequency will			
	A	Increase		Decrease
	C	Stay the same	D	Be zero
5	If the pendulum completes exactly 12 cycles in 2.0 min, what is the frequency of the pendulum?			
		0.10 Hz	B	0.17 Hz
	C	6.0 Hz	D	10 Hz
6	A certain pendulum has an iron bob. When the iron bob is replaced with lead bob of the same size, its time period will			
		Stay the same	B	Decrease
	C	Increase	D	Be zero
7	A wave transports			
		Energy but not Matter	B	Matter but not Energy
	C	Both energy and Matter	D	Air
8	The bending of waves around the edges of the obstacle is			
	A	Reflection	B	Refraction
		Diffraction	D	Damping

Conceptual Questions

1. Is every oscillatory motion simple harmonic?
Give examples.

Ans. No, oscillatory motion means any kind of to and fro motion. Whereas, SHM is a special kind of oscillatory motion in which the restoring force must always be directly proportional to the displacement from mean position and always be directed towards the mean position.

$$\text{i.e. } F_{\text{res}} \propto -x$$

Example # 1: When a ball is dropped from a height, the motion of ball is oscillatory but not simple harmonic because the restoring force $F_{\text{res}} = mg$ which is always constant but not directly proportional to the displacement.

Example # 2: The motion of mass attached to a spring is oscillatory as well as simple harmonic because the elastic restoring force in case of mass-spring system satisfies the conditions of SHM.



2. For a particle with simple harmonic motion, at what point of the motion does the velocity attain maximum magnitude? Minimum magnitude?

Ans. The total energy of the simple harmonic oscillator at any instant is the sum of K.E. and P.E. which remains always constant. As we know that the K.E. of the simple harmonic oscillator is maximum at mean position while zero at extreme positions, so its velocity will also be maximum at mean position while zero at extreme positions.



3. Is the restoring force on a mass attached to spring in simple harmonic motion ever zero? If so, where?

Ans. As we know that

$$F_{\text{res}} = -kx \dots \dots \dots (1)$$

At mean position, $x = 0$,

$$(1) \Rightarrow F_{\text{res}} = k(0)$$

$$F_{\text{res}} = 0$$

Yes, the restoring force on a mass attached to spring in SHM becomes zero at mean position.

4. If we shorten the string of a pendulum to half its original length, what is the effect on its time period and frequency?

Ans. As we know that

$$T = 2\pi\sqrt{\frac{l}{g}} \dots\dots\dots(1)$$

If the length of the pendulum is halved (i.e. $l' = \frac{l}{2}$) then

$$(1) \Rightarrow T' = 2\pi\sqrt{\frac{l'}{g}} \quad (\text{Put } l' = \frac{l}{2})$$

$$T' = 2\pi\sqrt{\frac{l/2}{g}} = 2\pi\sqrt{\frac{l}{2g}} = 2\pi\left(\frac{1}{\sqrt{2}} \times \sqrt{\frac{l}{g}}\right)$$

$$T' = \frac{1}{\sqrt{2}} \times 2\pi\sqrt{\frac{l}{g}} \dots\dots\dots(2)$$

Putting equation (1) in (2), we get,

$$T' = \frac{T}{\sqrt{2}}$$

So, the time period of the simple will decrease by the factor $\frac{1}{\sqrt{2}}$.

We also know that

$$f = \frac{1}{T} \dots\dots\dots(3)$$

$$(1) \Rightarrow f' = \frac{1}{T'} \quad (\text{Put } T' = \frac{T}{\sqrt{2}})$$

$$f' = \frac{1}{T/\sqrt{2}} = \frac{\sqrt{2}}{T}$$

$$f' = \sqrt{2} \times \frac{1}{T} \dots\dots\dots(4)$$

Putting equation (3) in (4), we get

$$f' = \sqrt{2} f$$

The frequency of the simple will increase by the factor $\sqrt{2}$.

5. A thin rope hangs from dark high tower so that its upper end is not visible. How can the length of rope be determined?

Ans. The length of the rope can be measured by attaching a mass to its lower end, so that it behaves like a pendulum.

As we know that

$$T = 2\pi\sqrt{\frac{l}{g}} \quad (\text{Squaring both sides})$$

$$T^2 = 4\pi^2 \left(\sqrt{\frac{l}{g}} \right)^2 = 4\pi^2 \frac{l}{g}$$

$$T^2 = \frac{4\pi^2 l}{g}$$

$$\Rightarrow l = \frac{gT^2}{4\pi^2} \dots\dots\dots(1)$$

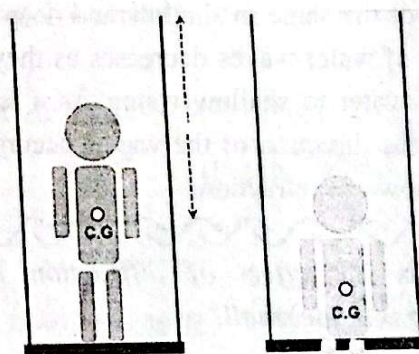
In the above equation, only time period is unknown which can be found by using a stopwatch.

6. Suppose you stand on a swing instead of sitting on it. Will your frequency of oscillation increase or decrease?



CONCEPT

(Optional)



Ans. As we know that the swing behaves like a simple pendulum, so its frequency is given by

$$f = \frac{1}{2\pi} \sqrt{\frac{g}{l}} \dots\dots\dots(1)$$

Here, l is the length of the swing which is equal to the distance from the point of suspension to centre of gravity (C.G.) of the person.

As the person stands on the swing, the C.G. rises up and the length decreases. According to equation (1), the frequency increases as the length decreases.

7. Explain the difference between the speed of a transverse wave travelling along a cord and the speed of a tiny colored part of the cord.

Ans. As the transverse wave travels along a cord, the particles of the cord vibrate perpendicular to the direction of propagation of the wave. If the cord has uniform density then the wave will travel with uniform speed.

However, the speed of the particles of the cord continuously changes. So the speed of the tiny colored particle is maximum at equilibrium position while zero at extreme positions.

8. Why waves refract at the boundary of shallow and deep water?

Ans. The speed of a wave depends upon the properties of the medium through which it travels. As shallow water and deep water provide two different media, therefore, the speed of water waves is not the same in shallow and deep water. The speed of water waves decreases as they enter from deep water to shallow water. As a result, a change in the direction of the waves occurs. This effect is known as refraction.

9. What is the effect of diffraction if the opening is made small?

Ans. Diffraction can be observed significantly if the size of the opening (slit) is comparable with the wavelength of the wave. So the diffraction occurs more significantly if the opening is made small, i.e. making its size comparable with the wavelength of the wave.

Numerical Questions

1. A mass hung from a spring vibrates 15 times in 12 s. Calculate (a) the frequency and (b) the period of the vibration.

Given data :

Number of vibrations 'N' = 15

Time 't' = 12 s

Required:

a) Frequency 'f' = ?

b) Time Period 'T' = ?

Solution :

a) As we know that

$$f = \frac{N}{t} \quad (\text{Put the values})$$

$$f = \frac{15}{12}$$

$$f = 1.25 \text{ Hz}$$

b) We also know that

$$T = \frac{1}{f} \quad (\text{Put the values})$$

$$T = \frac{1}{1.25}$$

$$T = 0.8 \text{ s}$$

2. A spring requires a force of 100.0 N to compress it to a displacement of 4 cm. What is its spring constant?

Given data :

Force 'F' = 100.0 N

Displacement 'x' = 4 cm

$$= 4 \times 10^{-2} \text{ m}$$

Required :Spring constant ' k ' = ?**Solution :**

As we know that

$$F = kx$$

$$\Rightarrow k = \frac{F}{x} \quad (\text{Put the values})$$

$$k = \frac{100.0}{4 \times 10^{-2}}$$

$$k = 25 \times 10^2 \text{ N/m}$$

$$k = 2500 \text{ N/m}$$



3. A second pendulum is a pendulum with time period of 2.0 s. How long must a second pendulum be on Earth ($g=9.8 \text{ m/s}^2$) and Moon (where $g=1.62 \text{ m/s}^2$)? What is the frequency of second pendulum at Earth and on Moon?

Given data :Time period ' T_E ' = 2.0 s

Acceleration due to gravity on earth

$$'g_E' = 9.8 \text{ m/s}^2$$

Acceleration due to gravity on moon

$$'g_M' = 1.62 \text{ m/s}^2$$

Required :

- Length on earth ' l_E ' = ?
- Length on moon ' l_M ' = ?
- Frequency on earth ' f_E ' = ?
- Frequency on moon ' f_M ' = ?

Solution :

As we know that

$$T = 2\pi \sqrt{\frac{l}{g}}$$

$$\Rightarrow T^2 = 4\pi^2 \left(\frac{l}{g} \right) \quad (\text{Squaring both sides})$$

$$\Rightarrow l = \frac{gT^2}{4\pi^2} \dots\dots\dots (1)$$

a)

$$(1) \Rightarrow l_E = \frac{g_E T^2}{4\pi^2}$$

$$\Rightarrow l_E = \frac{(9.8)(2)^2}{4 \times (3.142)^2}$$

$$\Rightarrow l_E = 0.99 \text{ m}$$

b)

$$(1) \Rightarrow l_M = \frac{g_M T^2}{4\pi^2}$$

$$\Rightarrow l_E = \frac{(1.62)(2)^2}{4 \times (3.142)^2}$$

$$\Rightarrow l_E = 0.16 \text{ m}$$

c & d)

As given that $T_E = T_M = T = 2.0 \text{ sec}$

$$\text{so} \quad f_E = f_M = f = \frac{1}{T} = \frac{1}{2.0}$$

$$f = 0.5 \text{ Hz}$$



4. Calculate the period and frequency of a propeller on a plane if it completes 250 cycles in 5.0 s.

Given data :Number of vibrations ' N ' = 250Time ' t ' = 5.0 s**Required :**

- Frequency ' f ' = ?
- Time period ' T ' = ?

Solution :

a) As we know that

$$f = \frac{N}{t} \quad (\text{Put the values})$$

$$f = \frac{250}{5.0}$$

$$f = 50 \text{ Hz}$$

b) We also know that

$$T = \frac{1}{f} \quad (\text{Put the values})$$

$$T = \frac{1}{50}$$

$$T = 0.02 \text{ s}$$

5. Water waves with wavelength 2.8 m, produced in a ripple tank, travel with a speed of 3.80 m/s. What is the frequency of the straight vibrator that produced them?

Given data :

Wavelength ' λ ' = 2.8 m

Speed ' v ' = 3.80 m/s

Required :

Frequency ' f ' = ?

Solution :

As we know that

$$v = f\lambda$$

$$\Rightarrow f = \frac{v}{\lambda} \quad (\text{Put the values})$$

$$\Rightarrow f = \frac{3.80}{2.8}$$

$$\Rightarrow f = 1.4 \text{ Hz}$$



6. The distance between successive crests in a series of water waves is 4.0 m, and the crests travel 9.0 m in 4.5 s. what is the frequency of the wave?

Given data :

Wavelength ' λ ' = 4.0 m

Distance ' S ' = 9.0 m

Time ' t ' = 4.5 s

Required :

Frequency ' f ' = ?

Solution :

As we know that

$$v = f\lambda$$

$$\Rightarrow f = \frac{v}{\lambda} \dots\dots\dots(1)$$

We also know that

$$v = \frac{S}{t} \quad (\text{Put the values})$$

$$v = \frac{9.0}{4.5} = 2.0 \text{ m/s}$$

Now put the values in equation (1)

$$(1) \Rightarrow f = \frac{2.0}{4.0}$$

$$f = 0.5 \text{ Hz}$$



7. A station broadcasts an AM radiowave whose frequency is $1230 \times 10^3 \text{ Hz}$ (1230 kHz on the dial) and an FM radiowave whose frequency is $91.9 \times 10^6 \text{ Hz}$ (91.6 MHz on the dial). Find the distance between adjacent crests in each wave.

Given data :

Frequency of AM ' f_{AM} ' = $1230 \times 10^3 \text{ Hz}$

Frequency of FM ' f_{FM} ' = $91.6 \times 10^6 \text{ Hz}$

Speed of Radiowaves ' c ' = $3 \times 10^8 \text{ m/s}$

Required :

a) Wavelength of AM ' λ_{AM} ' = ?

b) Wavelength of FM ' λ_{FM} ' = ?

Solution :

As we know that

$$v = f\lambda$$

$$\Rightarrow \lambda = \frac{v}{f} \dots\dots\dots(1)$$

$$a) \quad (1) \Rightarrow \lambda_{AM} = \frac{v}{f_{AM}} \quad (\text{Put the values})$$

$$\lambda_{AM} = \frac{3 \times 10^8}{1230 \times 10^3}$$

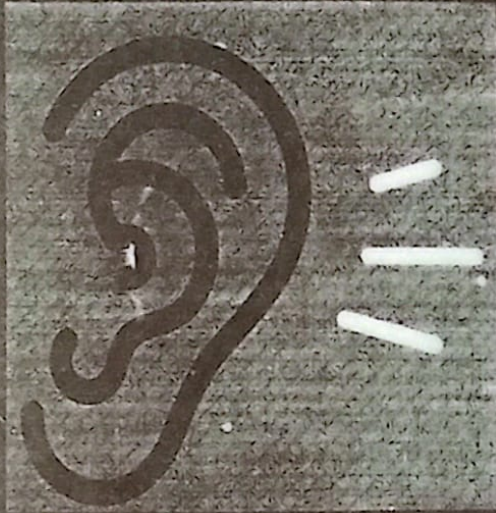
$$\lambda_{AM} = 244 \text{ m}$$

$$b) \quad (1) \Rightarrow \lambda_{FM} = \frac{v}{f_{FM}} \quad (\text{Put the values})$$

$$\lambda_{FM} = \frac{3 \times 10^8}{91.6 \times 10^6}$$

$$\lambda_{FM} = 3.27 \text{ m}$$





UNIT 11

SOUND

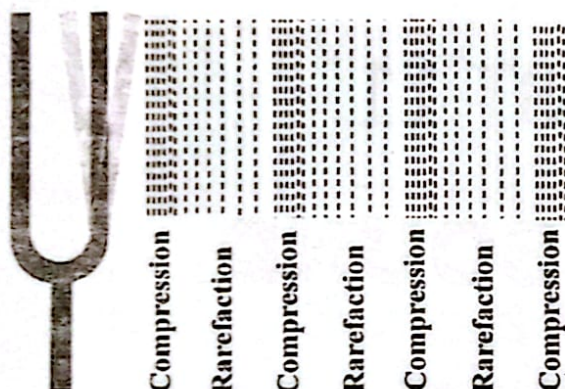
Sound

The sensation perceived by the sense of hearing is called sound. It is a form of energy which is transferred from one place to another due to longitudinal waves.

Sound Waves

Sound waves are longitudinal mechanical waves which require a material medium (Solid, liquid and gas) for its propagation.

Consider a *tuning fork* (a device used in laboratory for producing pure musical note) as shown below.



When a tuning fork is struck, its prongs (or tines) start vibrating. Their vibration disturbs the air near them and produce sound.

Consider the right prong. When it moves to the right, the layers of air are forced closer together than normal. Such a region of high pressure and density is called *compression*. When the prong moves to the left, the layers of air to its right side spread apart. Such a region of lower pressure and density than normal is called *rarefaction*. The rarefaction follows the previously produced compression. As long as the prong vibrates, a succession of compressions and rarefaction are produced and propagate through air.

Production, Transmission and Detection of Sound

Production of Sound

Sound waves are produced by vibrating bodies.

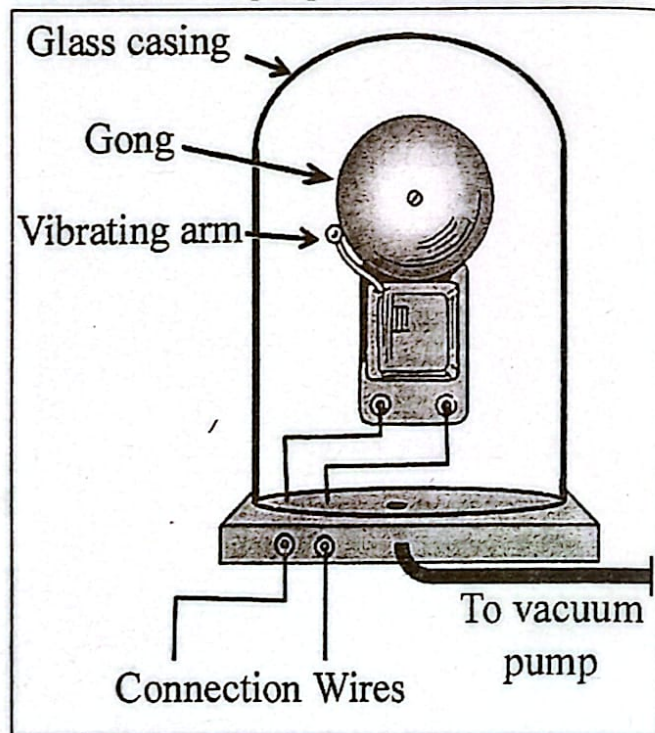
All the sources of sound have some part that vibrates. For example, the buzzing sound of mosquito is due to the vibration of its wings, the sound of guitar is due to the vibration of its stretched strings, the human voice is due to the vibration of the vocal cords, etc.

Transmission of Sound

Since sound waves are mechanical waves, they require material medium for propagation. Sound can be transmitted through solids, liquids and gases. For example, children while playing may observe that sound travels very easily along the metal fence. Swimmers can hear the sound of a distant motorboat better under water than in air.

In short, sound requires a material medium for its propagation and cannot travel through vacuum.

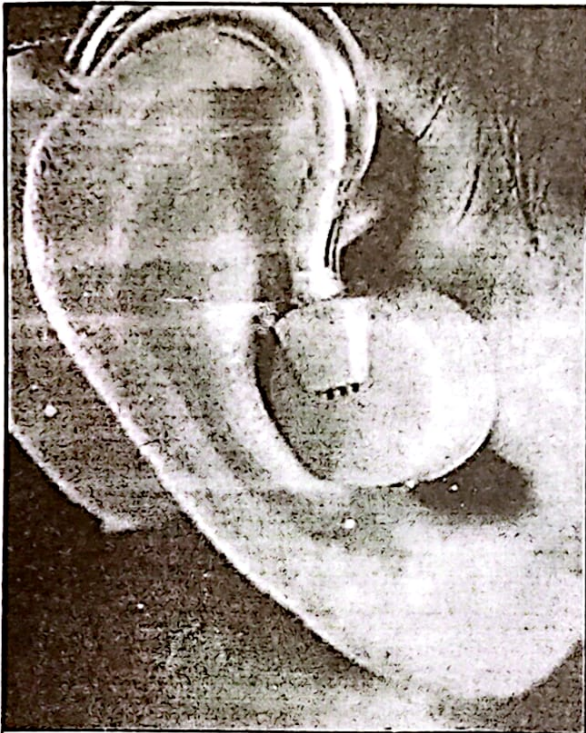
Consider glass jar containing a ringing electric bell and a vacuum pump is fitted as shown below.



By pumping the air out of the jar, the sound disappears though the vibrating arm can still be seen hitting the gong. So, we can conclude that sound cannot travel in a vacuum.

Detection of Sound

Sound can be detected by ear (a biological device) as well as various artificial devices. When the sound waves fall on ear drum, it starts vibrating. The ear converts these vibrations into perception of hearing. The persons with impaired hearing detect sound with artificial hearing devices.



artificial hearing device

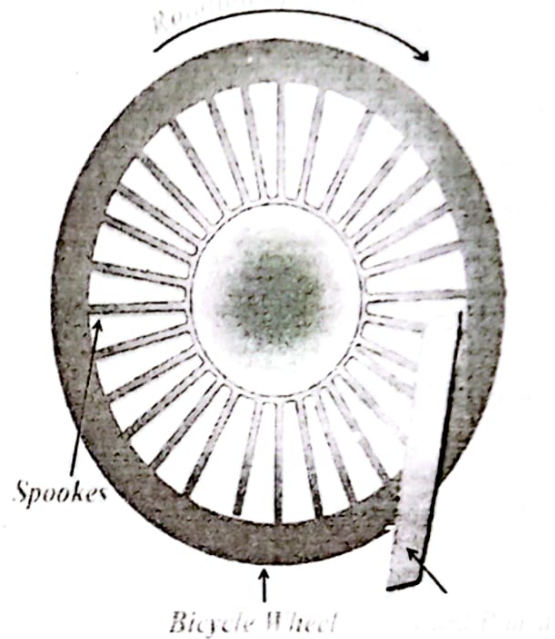
Characteristics of Sound

Pitch of sound

The characteristic of sound which distinguishes shrill sound from grave sound is called pitch.

Pitch of sound depends upon frequency. The higher the frequency the higher will be the pitch and shriller will be the sound, and vice-versa.

Consider a rotating bicycle wheel. If we hold a piece of cardboard just touching the spokes of the wheel. A sound produces when the spokes hit the cardboard. As we increase the speed of rotation, the frequency increases. As a result the sound produced will be shriller (i.e. higher pitch).



Loudness of Sound

The characteristic of sound which distinguishes loud sound from faint sound is called loudness.

Loudness of sound depends upon the amplitude. Larger the amplitude, greater will be the energy and hence louder will be the sound, and vice-versa.

Following are the factors upon which the loudness depends.

Area of the vibrating body: Larger the area of the vibrating body, larger will be amplitude (loudness) of the sound.

Distance from the source of sound: Farther away the source of sound, smaller will be the amplitude (loudness) of sound.

Material through which sound is travelling: Amplitude of sound is different in different materials such as air and water.

Quality of sound

The characteristic of sound which distinguishes sounds of same pitch and loudness is called Quality.

Sound

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Production, Transmission and Detection of Sound

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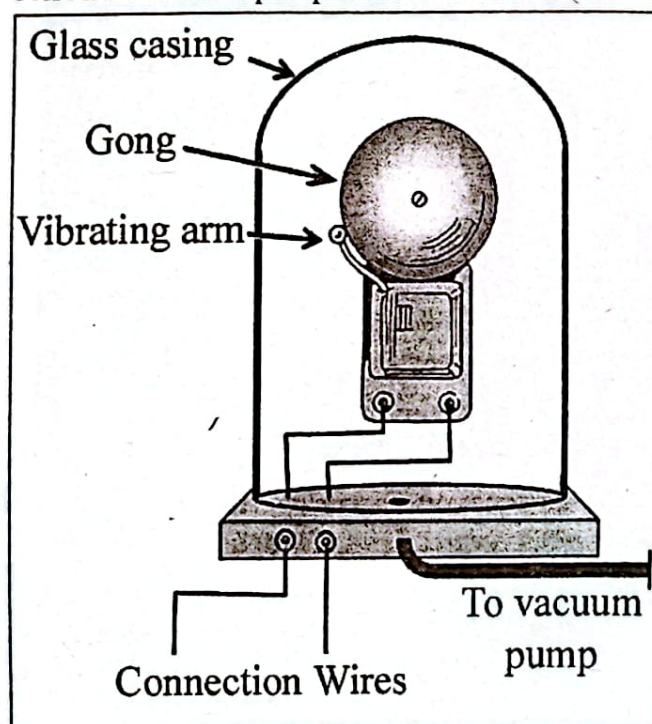
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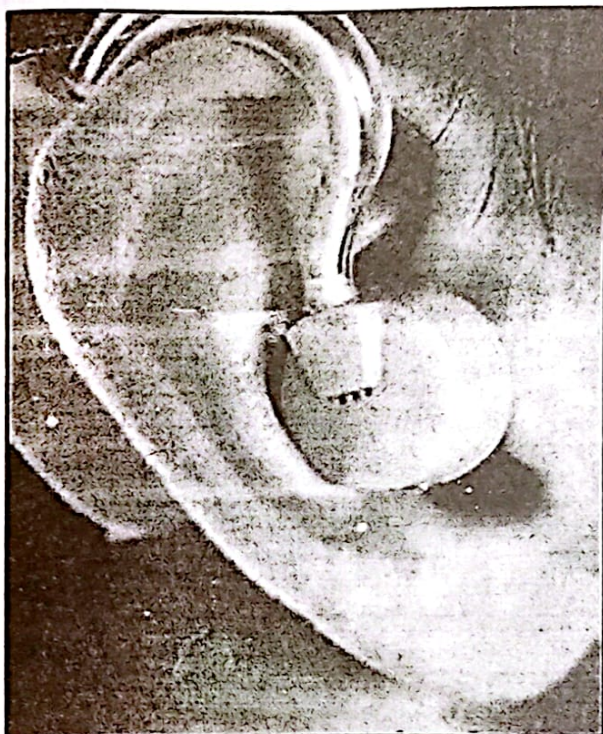
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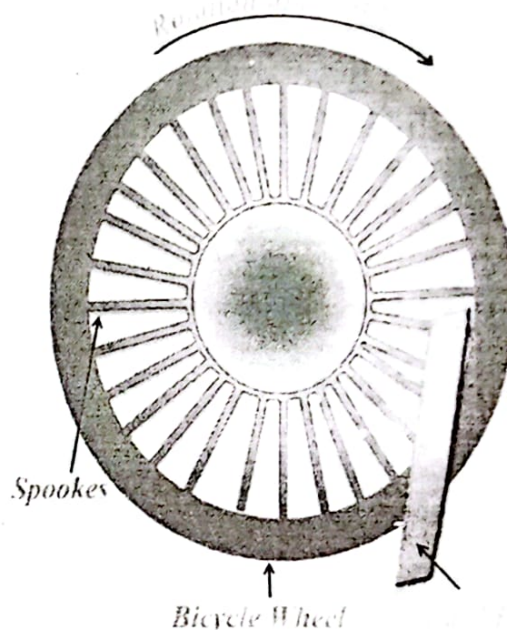
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Material through which sound is travelling: Amplitude of sound is different in different materials such as air and water.

Quality of sound

The characteristic of sound which distinguishes sounds of same pitch and loudness is called Quality.

A note (sound of same pitch and loudness) played on different instruments sounds different. For example, when a piano and flute are played simultaneously to produce sound of same pitch and loudness, we can easily distinguish between the sounds because they differ in quality (or timbre).



Sound Intensity

Intensity of sound is defined as: the energy carried by sound per unit area per unit time.

$$\text{i.e. } I = \frac{E}{A \times \Delta t} \quad \dots\dots\dots(1)$$

$$\Rightarrow I = \frac{1}{A} \times \frac{E}{\Delta t} \quad (\because P = \frac{W}{\Delta t} = \frac{E}{\Delta t})$$

$$\Rightarrow I = \frac{P}{A} \quad \dots\dots\dots(2)$$

Unit of Sound Intensity

$$(2) \Rightarrow [I] = \frac{[P]}{[A]} = \frac{\text{watt}}{\text{square meter}} = \boxed{W m^{-2}}$$

Intensity of sound is an objective property of the sound wave. It means that it is related to the amplitude (energy) of the sound and does not the characteristic of the ear of a person.

It is experimentally proved that the loudness of sound is directly proportional to the logarithm of its intensity.

$$\text{i.e. } L \propto \log I$$

$$\Rightarrow L = k \log I \quad \dots\dots\dots(3)$$

Intensity Level / Sound Level

The difference between the loudness of a given sound 'L' and loudness of the faintest audible sound 'L₀' is called intensity level of that sound, denoted by 'β'.

$$\text{i.e. } \beta = L - L_0 \quad \dots\dots\dots(4)$$

$$\text{where, } L = k \log I \quad \text{and } L_0 = k \log I_0$$

$$(4) \Rightarrow \beta = k \log I - k \log I_0$$

$$\Rightarrow \beta = k (\log I - \log I_0) \quad \dots\dots\dots(5)$$

$$\text{Applying log property } \log a - \log b = \log \left(\frac{a}{b} \right)$$

$$(5) \Rightarrow \beta = k \log \frac{I}{I_0} \quad \dots\dots\dots(6)$$

If the intensity of a given sound is ten times greater than the intensity of the faintest audible sound ($I = 10I_0$), then the intensity level of such a sound is 1 bel and the value of 'k' becomes 1.

$$(6) \Rightarrow \beta = \log \frac{I}{I_0} \text{ (bels)} \quad \dots\dots\dots(7)$$

Since *bel* is a large unit, a convenient unit used for the intensity level is *decibel* (dB) such that 1 bel = 10 dB

$$(7) \Rightarrow \beta = 10 \log \frac{I}{I_0} \text{ (dB)} \quad \dots\dots\dots(8)$$



Speed of Sound Waves

Speed of sound is defined as: the distance travelled by a sound wave per unit time as it propagate through a medium.

Speed of sound is different in different media. For example,

- Speed of sound is the greatest in solids (e.g. about 5000 m/s in steel).
- Speed of sound in liquids is lower than in solids (e.g. about 1500 m/s in water).
- Speed of sound is the lowest in gases (e.g. about 340 m/s in air).

The above examples shows that the speed of sound in water is about 5 times greater than its

speed in air. It is according to the relation for the speed of longitudinal waves

$$v = \sqrt{\frac{E}{\rho}}$$

the more the medium is elastic, the greater is the speed of sound in it.

Speed of Sound in Air

Since sound waves are longitudinal waves, its speed is given by

$$v = \sqrt{\frac{E}{\rho}}$$

Which shows that the speed of sound in air depends upon the compressibility and density of air. As these properties of air change with the variation in temperature, so the speed of sound also varies with temperature. At a temperature of 0°C and atmospheric pressure of 1 atm, the speed of sound in dry air is 331 m/s and increases by 0.6 m/s for each 1°C rise in temperature.

Mathematically

$$v = 331 + 0.6T$$

Where ' T ' is the temperature in $^\circ\text{C}$. For example the speed of sound in air at 20°C can be calculated as:

$$v = 331 + 0.6(20)$$

$$\Rightarrow v = 331 + 12$$

$$\Rightarrow v = 343 \text{ m/s}$$

Speed of sound in a medium is the same for all frequencies. According to the universal wave equation

$$v = f\lambda$$

if the frequency of a wave is doubled, its wavelength is halved, so that the speed stays the same.

Reflection of Sound Waves

The bouncing back of sound waves from a surface is called reflection of sound.

Sound waves are reflected well from hard and smooth surfaces while absorb in soft materials more than they reflect. The reflected sound is called echo but if the reflecting surface is nearer than about 17 m, then it joins with the original sound and is called reverberation.

Echo

A reflected sound that can be distinguished from the original sound is called echo.

The human ear can distinguish the reflected sound from the original sound only if it is heard after 0.1 second. So, the reflected sound heard after 0.1 second is an echo while the sound heard before 0.1 second is called reverberation.

The minimum distance of the reflecting surface to produce an echo can be calculated as

$$v = \frac{2S}{\Delta t}$$

$$\text{Or } S = \frac{v\Delta t}{2} \dots\dots\dots(1)$$

In case of echo, the sound covers twice distance, so we take distance equal to $2S$.

$$\text{Speed of sound 'v' = } 340 \text{ m/s}$$

$$\text{Time 't' = } 0.1 \text{ s}$$

Put the values in equal (1), we get

$$S = 17 \text{ m}$$

Since speed of sound changes with the variation in temperature, so the change in temperature can affect this distance.

Acoustics

Acoustics is branch of physics which deals with the production, control, transmission, reception and effects of sound.

Echoes are easily observed in a large empty room, but when there exist materials and surfaces that absorb sound, the sound level will be too low that the room will sound dull. Some reflected sound is desirable in rooms, concert halls and auditoriums to make these places sounding full and lively, but too much reflection of sound can cause confusion.

The goal of acoustics is to achieve desired amount of reflection of sound in these places. For example;

- In theaters, a highly reflective surface is placed behind the stage to direct sound out to audience.
- Noise is suppressed in offices and homes to make them comfortable places to work and live.

The acoustics of a room depends on its shape, the composition of walls, ceiling, floor and materials exist in it. For example, flat surfaces reflect, parabolic surfaces focus, porous surfaces absorb and jagged surfaces disperse the sound.

Acoustic Protection

Acoustic protection is about protection of humans, animals, birds and structures against undesirable sounds and noises.

- It is employed to protect physical health as well as psychological well-being of humans.
- It is required to protect animals and birds because they also express discomfort due to higher noise and sound levels.
- It is required to protect structures such as bridges and buildings against the vibrations generated by objects such as trains and earthquakes.



Audible Frequency Range

Humans can hear only sounds with frequencies from 20 Hz to 20,000 Hz. This range of frequencies is called audible frequency range. The upper limit (i.e. 20,000 Hz) decreases with age.

Infrasonic / Infrasound

Sounds having frequency lower than 20 Hz are known as Infrasonds.

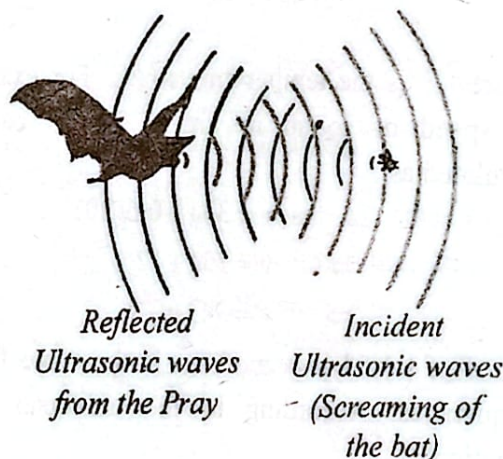
Various animals such as Whales, Elephants, Rhinoceroses use infrasound to communicate over long distances. The range of communication for elephants via infrasound is about 10 km while hundreds of kilometers for whales.

Infrasonds are also generated by human activities such as explosions and machinery.

Ultrasonic / Ultrasound

Sounds having frequency higher than 20,000 Hz are known as ultrasounds.

Bats can produce and hear ultrasounds while screaming to detect their prey. This phenomenon is known as echolocation.



They can detect frequencies upto 200 kHz. Some insects such as moths, beetles, praying mantids, etc., can also detect ultrasounds. When they hear bats, they escape and protect themselves from echolocating bats.

Applications of Ultrasounds

1. Automatic door opener:

Ultrasonic sensors are installed above the door. When it detects a person approaching to it, it opens the door automatically.

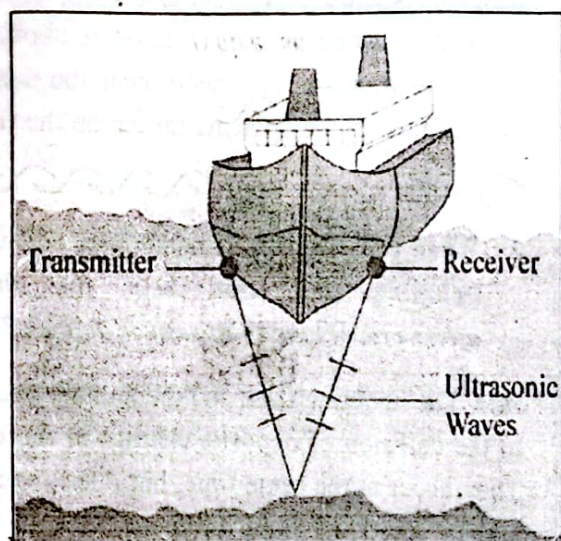
2. Non-destructive testing:

In industry, ultrasonic testing is used to find flaws in materials and to measure the thickness of sheets.

3. SONAR:

SONAR stands for "Sound Navigation and Ranging".

A transmitter transmits an ultrasonic pulse in a particular direction. This pulse reflects from objects forming an echo which is detected by receiver. By measuring the difference in time between the transmitted and received pulses, it is possible to determine the distance.



4. Ultrasonic cleaners:

Ultrasonic cleaner is a device which uses ultrasound (usually from 20 kHz to 40 kHz) and water to clean delicate items. When ultrasound is passed through water, millions of tiny bubbles are created. The bubbles in contact with the surface of the item combine with each other (collapse) with a huge pressure and gives incredible cleaning results. This phenomenon is called *cavitation*.

EXERCISE

Multiple Choice Questions

1	The intensity of a sound wave increases by 1000 W/m ² . What is this increase equal to in decibels?			
	A	10	B	20
		30	D	40
2	An echo occurs when a sound wave is			
	A	Absorbed	B	Transmitted
	C	Refracted	D	Reflected
3	Compared with a sound of 60 decibels, a sound of 80 decibels has an intensity _____ times greater.			
	A	10	B	100
	C	1000	D	10,000
4	The loudness of a sound is most closely related to its			
	A	Frequency	B	Period
		Wavelength	D	Amplitude
5	Various instruments sound different even when they play the same note due to difference in			
	A	Pitch	B	Loudness
	C	Quality	D	Intensity
6	Humans can hear sound that is			
	A	Less than 20 Hz	B	Between 20 Hz and 20 kHz
	C	Greater than 20 kHz	D	None
7	The speed of sound on a warm day when the outdoor temperature is 38 °C is			
	A	331 m/s	B	345 m/s
		354 m/s	D	362 m/s
8	Minimum echo distance is reduced in			
	A	Summer	B	Winter
	C	Spring	D	Space
9	Which of the following cannot transmit sound?			
	A	Solid	B	Liquid
	C	Gas	D	Vacuum

Conceptual Questions

1. Why sound produced by a simple pendulum is not heard?

Ans. Human ear can hear sounds of frequency higher than 20 Hz and lower than 20 kHz (called audible frequency range). Since the frequency of simple pendulum is lower than 20 Hz, therefore, we cannot hear the sound produced by simple pendulum.

2. If a ringing bicycle bell is held tightly by hand, it stops producing sound. Why?

Ans. A bicycle bell produces sound due to its vibration. When it is held tightly by hand, it stops vibration and hence stops producing sound.

3. Why is the intensity of an echo less than that of the original sound?

Ans. An echo is a reflected sound. When a sound wave strikes a surface, some of the energy carried by the wave is transferred to the surface and the remaining energy is carried back by the reflected waves. Thus the reflected wave (echo) possesses less energy and become less intense. Therefore, the intensity of an echo is always less than that of the original sound.

4. In which medium air or water, an echo is heard sooner? Why?

Ans. As we know that echo is a reflected sound and the speed of sound in a medium is given by

$$v = \sqrt{\frac{E}{\rho}}$$

The above equation shows that the speed of sound depends on the elasticity and density of the medium. Since, the elasticity of water is far

greater than its density as compared to air. So the sound waves will travel faster in water than air. That is why, the echo is heard sooner in water.

5. Why sound cannot be heard on the moon?

Ans. Sound waves are mechanical waves which require material medium for their propagation. Since moon has no atmosphere through which sound waves can pass. Thus sound cannot be heard on moon.

6. If a person places his ear on rails of railroad for determination of coming train. Why is this done, and how does it work?

Ans. As we know that the speed of sound waves is the highest in solids. For example, at standard temperature and pressure, the speed of sound in air is 331 m/s, while in steel (rails) it is about 5100 m/s. Thus a person can easily hear the sound of approaching train by placing his ear on the rails.

7. When you watch a thunderstorm, you see the lightning first, and hear the thunder afterward. Why is the thunder delayed?

Ans. The lightning flash and the thunder occur due to the collision of opposite charges in the clouds. They occur at the same time, but due to the much higher speed of light ($c = 3 \times 10^8$ m/s) than sound ($v = 332$ m/s), the lightning flash is seen before the thunder is heard.

8. If the speed of sound is dependent on frequency, would music from marching band be enjoyed?

Ans. The speed of sound depends only on the properties of the material medium through which it travels. It is independent of the frequency. If the speed of sound were dependent on frequency, the

sounds of different frequencies will not be heard at the same time. Thus the music played by marching band will not be enjoyed.



9. *Why does your voice sound fuller in the shower?*

Ans. The voice sounds fuller in the shower due to the effect of reverberation. Reverberation occurs due to the multiple reflections of the sound from the hard surfaces of the shower. This continuation of many reflections causes the sound to increase in volume.



10. *Why is it so quiet after a snowfall?*

Ans. Snow is a good absorber of sound because of its porous nature. When sound waves strike the snow surface, a considerable amount of sound energy is absorbed. That is why, it is so quiet after a snow fall.



Numerical Questions

1. The sound intensity 3 m from a jackhammer is $8.20 \times 10^{-2} \text{ W/m}^2$. What is the sound intensity level in decibel? (Use the usual reference level of $I_0 = 1.00 \times 10^{-12} \text{ W/m}^2$).

Given data :

Intensity of the sound ' I ' = $8.20 \times 10^{-2} \text{ W / m}^2$

Intensity of the faintest audible sound ' I_0 ' = $1.00 \times 10^{-12} \text{ W / m}^2$

Required :

Intensity level ' β ' = ?

Solution :

As we know that

$$\beta = 10 \log \left(\frac{I}{I_0} \right) \quad (\text{dB}) \quad (\text{Put the values})$$

$$\beta = 10 \log \left(\frac{8.20 \times 10^{-2}}{10^{-12}} \right) \quad (\text{dB})$$

$$\beta = 10 \log (8.20 \times 10^{10}) \quad (\text{dB})$$

$$\beta = 10 \times 10.914 \quad (\text{dB})$$

$$\beta = 109.14 \quad (\text{dB})$$



2. A ship is anchored where the depth of water is 120 m. An ultrasonic signal sent to the bottom of the lake returns in 0.16 s. what is the speed of sound in water?

Given data :

Depth ' S ' = 120 m

Time ' t ' = 0.16 s

Required :

Speed of sound ' v ' = ?

Solution :

As we know that

$$v = \frac{S}{t}$$

But in case of echo

$$v = \frac{2S}{t} \quad (\text{Put the values})$$

$$v = \frac{2 \times 120}{0.16}$$

$$v = 1500 \text{ m/s}$$



3. A gunshot from a .22 rimfire rifle has an intensity of about $I = (2.5 \times 10^{13}) I_0$. Do we need to wear ear protection? (Considering that prolonged exposure to sounds above 85 decibels can cause hearing damage or loss).

Given data :

$$\text{Intensity of the sound } 'I' = (2.5 \times 10^{13}) I_0$$

Required :

$$\text{Intensity level } '\beta' = ?$$

Solution :

As we know that

$$\beta = 10 \log \left(\frac{I}{I_0} \right) \quad (\text{dB}) \quad (\text{Put the values})$$

$$\beta = 10 \log \left(\frac{2.5 \times 10^{13} I_0}{I_0} \right) \quad (\text{dB})$$

$$\beta = 10 \log (2.5 \times 10^{13}) \quad (\text{dB})$$

$$\beta = 10 \times 13.4 \quad (\text{dB})$$

$$\beta = 134 \quad (\text{dB})$$

Since the intensity level is higher than 85 dB, so we need to wear ear protection



4. What sound intensity level in dB is produced by earphones that create an intensity $4.00 \times 10^{-2} \text{ W/m}^2$? (Use the usual reference level of $I_0 = 1.00 \times 10^{-12} \text{ W/m}^2$).

Given data:

$$\text{Intensity of the sound } 'I' = 4.00 \times 10^{-2} \text{ W/m}^2$$

Intensity of the faintest audible

$$\text{sound } 'I_0' = 1.00 \times 10^{-12} \text{ W/m}^2$$

Required:

$$\text{Intensity level } '\beta' = ?$$

Solution:

As we know that

$$\beta = 10 \log \left(\frac{I}{I_0} \right) \quad (\text{dB}) \quad (\text{Put the values})$$

$$\beta = 10 \log \left(\frac{4.00 \times 10^{-2}}{10^{-12}} \right) \quad (\text{dB})$$

$$\beta = 10 \log (4.00 \times 10^{10}) \quad (\text{dB})$$

$$\beta = 10 \times 10.602 \quad (\text{dB})$$

$$\beta = 106.02 \quad (\text{dB})$$



5. What is the speed of sound in air at -20°C ?

Given data:

$$\text{Temperature } 'T' = -20^\circ\text{C}$$

Required:

$$\text{speed of sound } 'v' = ?$$

Solution:

As we know that

$$v = 331 + 0.6T \quad (\text{Put the values})$$

$$v = 331 + 0.6(-20)$$

$$v = 331 + (-12)$$

$$v = 319 \text{ m/s}$$



6. Army man wearing binoculars see the flash from enemy tank fire 5 s before the fire is heard, he records 26°C temperature on his personal thermometer. What is the distance of the tank from him?

Given data:

$$\text{Time } 't' = 5 \text{ s}$$

$$\text{Temperature } 'T' = 26^\circ\text{C}$$

Required:

$$\text{Distance } 'S' = ?$$

Solution:

As we know that

$$S = vt \dots \dots \dots (1)$$

Where,

$$v = 331 + 0.6T \quad (\text{Put the values})$$

$$v = 331 + 0.6(26)$$

$$v = 331 + 15.6$$

$$v = 346.6 \text{ m/s}$$

Put the values in equation (1)

$$(1) \Rightarrow S = 346.4 \times 5$$

$$S = 1733 \text{ m}$$

$$S = 1.7 \text{ km}$$



7. Calculate the wavelengths of sounds at the extremes of the audible range. 20 Hz and 20,000 Hz, at normal room temperature of 20°C.

Given data:

Lowest Frequency ' f_L ' = 20 Hz

Highest Frequency ' f_H ' = 20,000 Hz

Temperature ' T ' = 20°C

Speed of sound at 20°C is calculated as

$$v = 331 + 0.6T$$

$$v = 331 + 0.6(20)$$

$$v = 331 + (12)$$

$$v = 343 \text{ m/s}$$

Required:

a) Lowest Wavelength ' λ_L ' = ?

b) Longest Wavelength ' λ_H ' = ?

Solution:

a) As we know that

$$v = f_H \lambda_L$$

$$\Rightarrow \lambda_L = \frac{v}{f_H} \quad (\text{Put the values})$$

$$\lambda_L = \frac{343}{20,000}$$

$$\lambda_L = 0.017 \text{ m}$$

$$\lambda_L = 1.7 \text{ cm}$$

b) We also know that

$$\lambda_H = \frac{v}{f_L} \quad (\text{Put the values})$$

$$\lambda_H = \frac{343}{20}$$

$$\lambda_H = 17 \text{ m}$$



8. Ishfaq stands between two high rise building A and B, such that he is at 33 m distance from building A. when he blow the whistle, he hears the first echo after 0.2 s and second echo after 0.8 s. calculate (a) the speed of sound and (b) distance of building B from him.

Given data:

Distance ' S_A ' = 33 m

Time taken ' t_A ' = 0.2 s

Time taken ' t_B ' = 0.8 s

Required :

a) Speed of sound ' v ' = ?

b) Distance ' S_B ' = ?

Solution :

a) As we know that

$$v = \frac{2S}{t}$$

$$\Rightarrow v = \frac{2S_A}{t_A} \quad (\text{Put the values})$$

$$v = \frac{2 \times 33}{0.2}$$

$$v = 330 \text{ m/s}$$

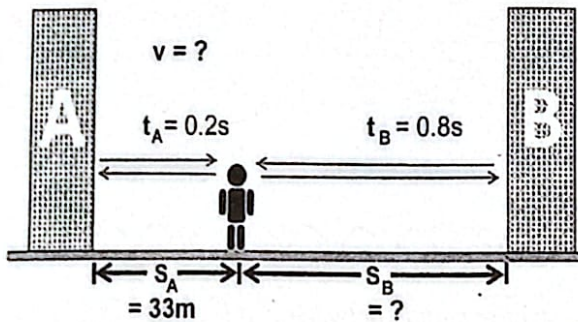
$$\text{b) As } v = \frac{2S}{t}$$

$$\Rightarrow S = \frac{vt}{2}$$

$$\Rightarrow S_B = \frac{v \times t_B}{2}$$

$$S_B = \frac{330 \times 0.8}{2}$$

$$S_B = 132 \text{ m}$$



Friedrich Chladni (November 30, 1756 - April 3, 1827) was a German physicist and musician who is considered by many historians to be the "Father of Acoustics".

Chladni was born in Wittenberg, Germany. Chladni's father, who was a professor of law at the University of Wittenberg, disapproved of his son's early interests in music and science and forced him to study law. Chladni duly obtained a law degree from the University of Leipzig in 1782. In the same year, following the death of his father, Chladni found himself free to pursue his interests in music and science, which he did with remarkable success.



UNIT 12

GEOMETRIC OPTICS

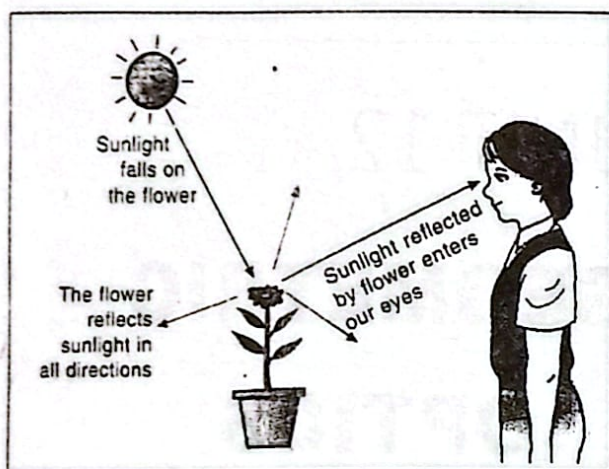
Optics

The branch of physics which deals with the study of light, its nature and properties is called optics.

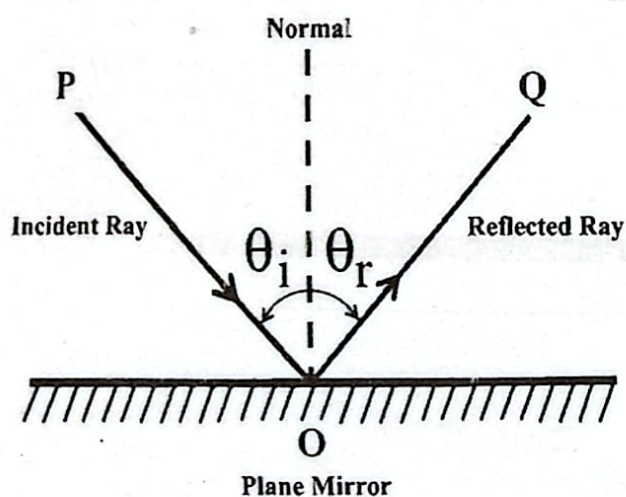
Reflection of Light

The bouncing back of light when it strikes a shiny surface is called reflection of light.

We see objects when light from luminous objects (Sun, electric lamps, candles, etc.) falls on them and reflect into our eyes.



Consider a ray of light falls on a flat, shiny surface such as mirror as shown below.



Following are the terms used in reflection of light.

1. Incident Ray

Line $\overline{PO}$ represents the incident ray. It is the approaching ray of light.

2. Reflected Ray

Line $\overline{OQ}$ represents the reflected ray. It is the ray of light reflected from a surface.

3. Point of Incidence

Point O represents the point of incidence. It is the point at which the incident ray strikes the reflecting surface.

4. Normal

It is the line drawn at point of incidence and is perpendicular to the surface.

5. Angle of Incidence

$\angle PON$ is the angle of incidence. It is the angle made by the incident ray with normal.

6. Angle of Reflection

$\angle QON$ is the angle of reflection. It is the angle made by the reflected ray with normal.

Laws of Reflection

First Law of Reflection

This law states that: the incident ray, reflected ray and normal at the point of incidence all lie in the same plane.

Second Law of Reflection

This law states that: the angle of reflection must be equal to the angle of incidence.

i.e.

$$\theta_i = \theta_r$$



Characteristics of Image

Following are the four characteristics which completely describe any image.

1. Magnification

Magnification is the ratio of the image size to the object size.

i.e.
$$M = \frac{h_i}{h_o}$$

If

$$M > 1 ; \text{ then } h_i > h_o$$

$$M = 1 ; \text{ then } h_i = h_o$$

$$M < 1 ; \text{ then } h_i < h_o$$

2. Attitude

Attitude of an image shows whether the image is upright or inverted with respect to the object.

3. Location (or Position)

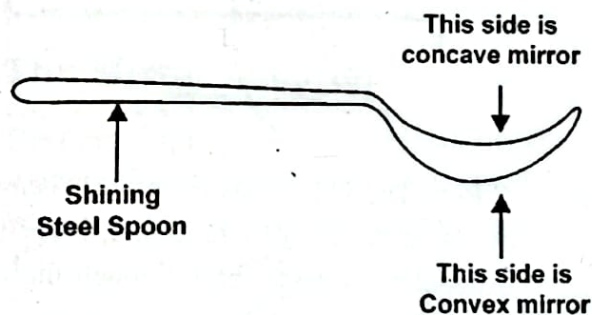
Location of image means the distance between the image and the optical device (i.e. mirror or lens).

4. Type

Type of image means whether the object is real or virtual. A *real image* is the one which is formed by the actual convergence of light rays. A *virtual image* is formed when the light rays appear to converge. The real image can be obtained on a screen while the virtual image cannot be obtained on a screen.

Spherical Mirrors

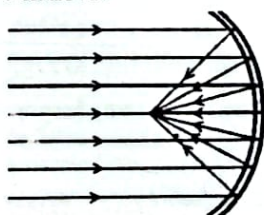
A spherical mirror has a shape of a section sliced from a hallow sphere with one side polished.



Concave Mirror

A spherical mirror whose concave (inside) surface is reflecting is called concave mirror.

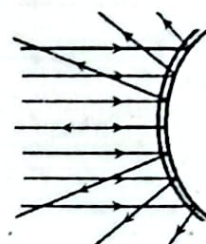
It is also called converging mirror because it converges light rays after reflection.



Convex Mirror

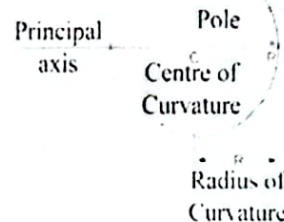
A Spherical mirror whose convex (outside) surface is reflecting is called convex mirror.

It is also called diverging mirror because it diverges light rays after reflection.



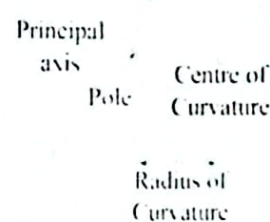
Terms related to Spherical Mirrors

Hallow Sphere of Glass



Concave Mirror

Hallow Sphere of Glass



Convex Mirror

1. Centre of Curvature

Centre of curvature is the centre of the hallow sphere of which the mirror is a part.

2. Radius of Curvature

Radius of curvature is the radius of the hallow sphere of which the mirror is a part.

3. Pole or Vertex

Pole is the central point of the mirror.

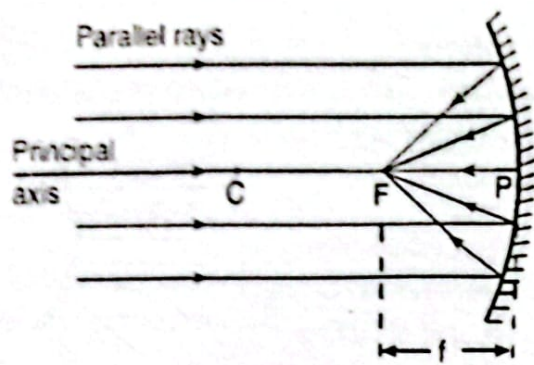
4. Principal axis

Principal axis the straight line drawn through the centre of curvature and pole of the mirror.

5. Principal Focus or Focal Point

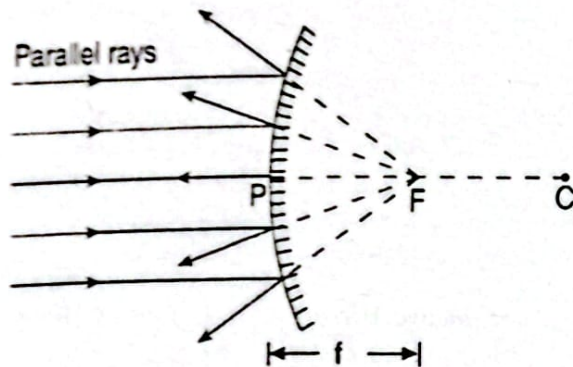
• Principal Focus of Concave Mirror

It is the point on principal axis at the front of a concave mirror at which a parallel beam of light converges (focuses) after reflection.



• **Principal Focus of Convex Mirror**

It is the point on principal axis behind a convex mirror from which a parallel beam of light appears to diverge after reflection.



6. Focal Length

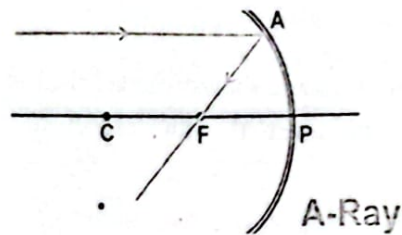
Focal length is the distance between the pole and principal focus of a mirror.

Image formation & Ray Diagram for Spherical Mirrors

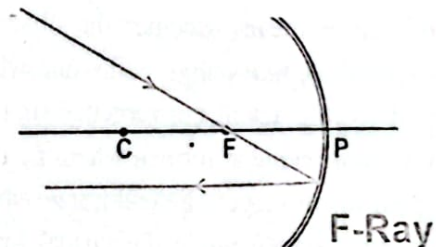
Following are the steps for drawing the ray diagram used to show image formation by a spherical mirror.

1. Draw a mirror and its principal axis showing principal point and centre of curvature.
2. Draw the object such that its one end lies on the principal axis.
3. Draw four special rays that arise from the tip of the object.

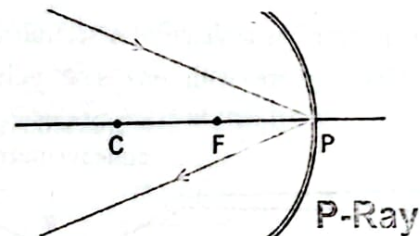
- i. **A-Ray:** The A-Ray initially parallel to principal axis and after reflection, it (or its extrapolation) passes through principal focus.



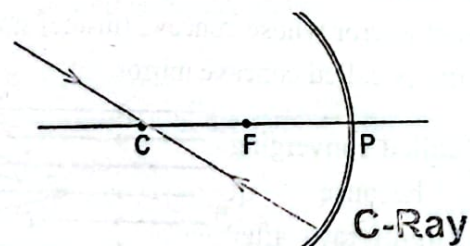
- ii. **F-Ray:** The F-Ray initially passes through principal focus and after reflection, it (or its extrapolation) passes parallel to principal axis.



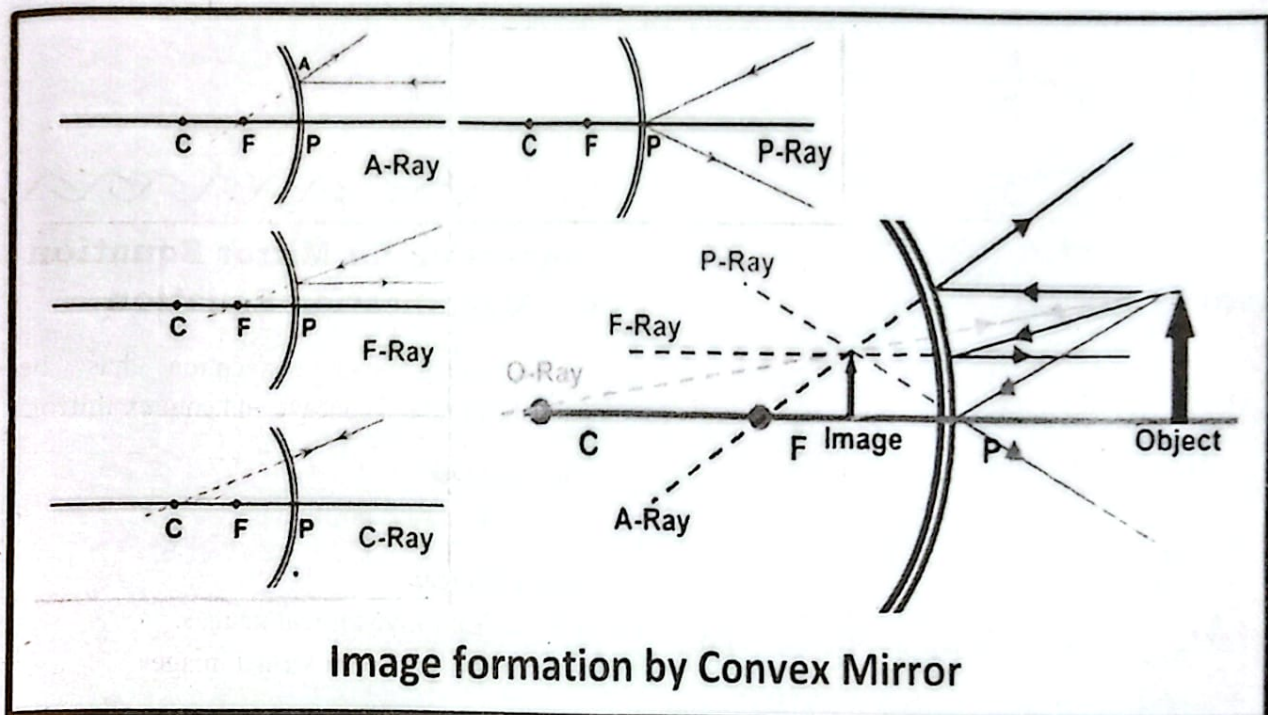
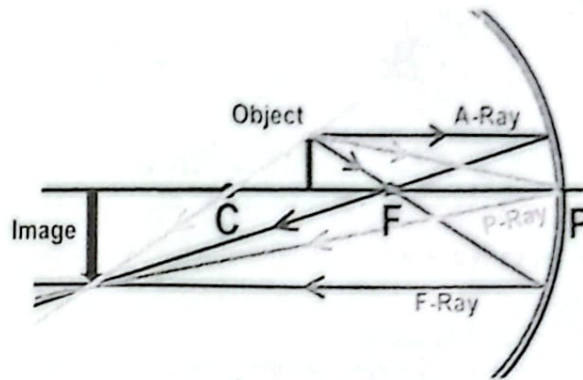
- iii. **P-Ray:** The P-Ray strikes the mirror at pole and reflects making an equal angle with the principal axis.



- iv. **C-Ray:** The C-Ray passes through centre of curvature and after reflection, it (or its extrapolation) passes back through the tip of the object.



4. The point where all the rays (A-Ray, F-Ray, P-Ray and C-Ray) intersect is the image point.



The Mirror Equation

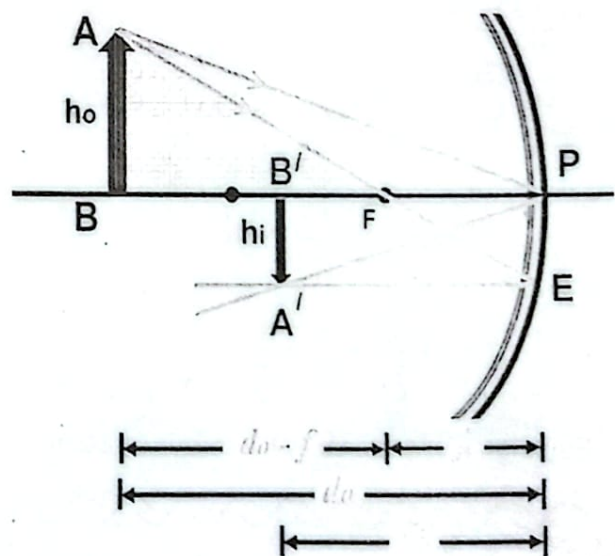
The mirror equation is a precise mathematical relationship between the object distance ' d_o ', the image distance ' d_i ' and focal length of the mirror ' f '.

In the figure:

- f = the focal length of the mirror
- h_o = the height of the object
- h_i = the height of the image
- d_o = the distance of object from the mirror
- d_i = the distance of image from the mirror

From the figure,

$$\triangle ABP \approx \triangle A'B'P$$



So,

$$\frac{AB}{A'B'} = \frac{BP}{B'P}$$

$$\Rightarrow \frac{h_o}{-h_i} = \frac{d_o}{d_i} \dots\dots\dots(1)$$

The negative sign of h_i indicates the inverted image.

Again from the figure,

$$\triangle ABF \approx \triangle EPF$$

So,

$$\frac{AB}{EP} = \frac{BF}{PF} \quad (\because EP = A'B' = h_i)$$

$$\Rightarrow \frac{h_o}{-h_i} = \frac{d_o - f}{f} \dots\dots\dots(2)$$

Comparing equations (1) and (2), we get

$$\frac{d_o}{d_i} = \frac{d_o - f}{f}$$

$$\Rightarrow d_o f = d_i (d_o - f)$$

$$\Rightarrow d_o f = d_i d_o - d_i f \dots\dots\dots(3)$$

Dividing both side by $d_o d_i f$

$$\Rightarrow \frac{\cancel{d_o} \cancel{f}}{\cancel{d_o} d_i \cancel{f}} = \frac{\cancel{d_i} \cancel{d_o}}{\cancel{d_o} \cancel{d_i} \cancel{f}} - \frac{\cancel{d_i} \cancel{f}}{d_o \cancel{d_i} \cancel{f}}$$

$$\Rightarrow \frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$$

$$\Rightarrow \frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \dots\dots\dots(4)$$

Equation (3) is known as the mirror equation.



Linear Magnification

The ratio of the height of the object to height of the image is called linear magnification.

Mathematically;

$$M = \frac{h_i}{h_o} \dots\dots\dots(1)$$

But we know that

$$\frac{h_o}{h_i} = \frac{d_o}{d_i}$$

$$\Rightarrow \frac{h_i}{h_o} = \frac{d_i}{d_o} \dots\dots\dots(2)$$

Equation (1) can be written as

$$M = \frac{h_i}{h_o} = \frac{d_i}{d_o}$$



Convention for Mirror Equation and Magnification Equation

The following sign convention has been established for both concave and convex mirror.

Object distance:

- d_o is always positive.

Image distance:

- d_i is positive for real images.
- d_i is negative for virtual images.

Image attitude:

- h_i is positive for upright images.
- h_i is negative for inverted images.

Focal length:

- Focal length of concave mirrors is positive.
- Focal length of convex mirrors is negative.



Dependence of Image's Features on the distance of the object d_o from the Concave mirror

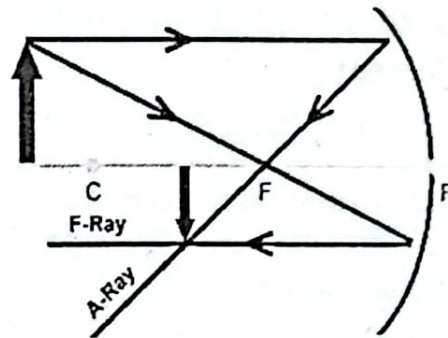
The features of the image (*magnification, attitude, location and type*) depends on the distance of the object from the mirror.

If the object is beyond

Centre of curvature (i.e. $d_o > r$)

then the image will be:

- *between C and F (i.e. $r > d_i > f$)*
- *real*
- *smaller than object*
- *inverted*

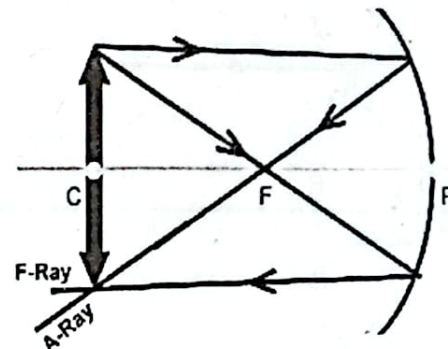


If the object is at

Centre of Curvature ($d_o = r$)

then the image will be:

- *at C ($d_i = r$)*
- *real*
- *same size*
- *inverted*

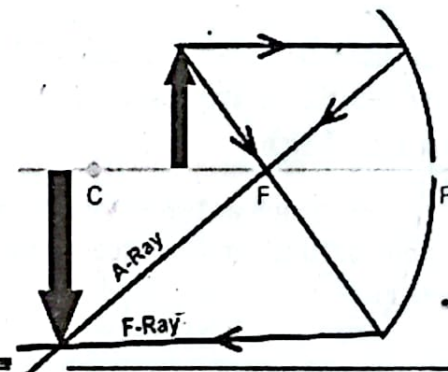


If the object is between

C and F ($r > d_o > f$)

then the image will be:

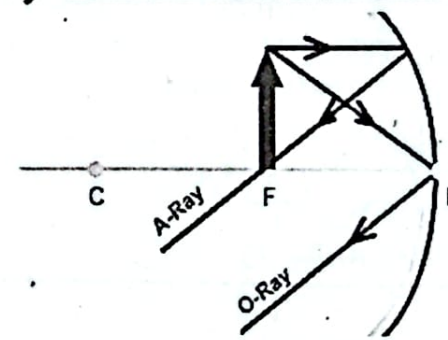
- *beyond C ($d_i > r$)*
- *real*
- *larger than object*
- *inverted*



If the object at

Principal Focus ($d_o = f$)

then *no image is formed at all.*

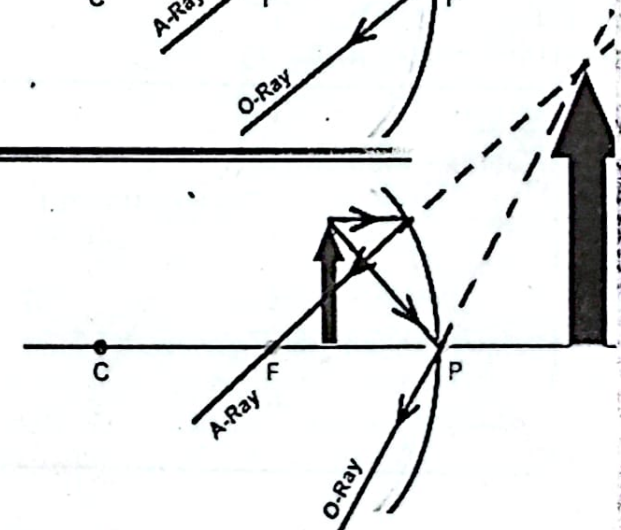


If the object is between

F and P ($f > d_o > 0$)

then the image will be:

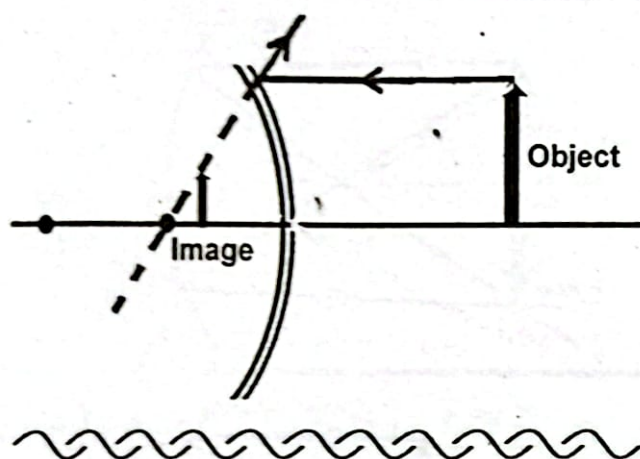
- *behind the mirror (d_i is negative)*
- *virtual*
- *highly Magnified*
- *upright*



Features of Image Formed by a Convex Mirror

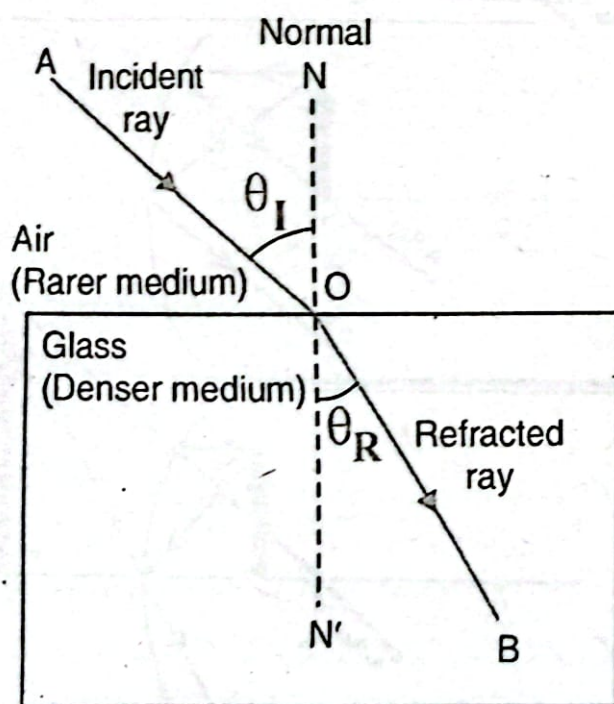
The image formed by a convex mirror is always:

- Behind the mirror (d_i is negative)
- Virtual
- Smaller than object
- Upright



Refraction of Light

The change in the direction and speed of light ray as it moves from one medium to another is called refraction of light.



Following are the terms related to refraction of

1. Incident Ray

Line $\overline{AO}$ represents the incident ray. It is the approaching ray of light.

2. Refracted Ray

Line $\overline{OB}$ represents the refracted ray. It is the ray of light moving away from the interface (boundary) between the two media.

3. Point of Incidence

Point O represents the point of incidence. It is the point at which the incident ray strikes the interface between the two media.

4. Normal

It is the line drawn at point of incidence and is perpendicular to the interface.

5. Angle of Incidence θ_I

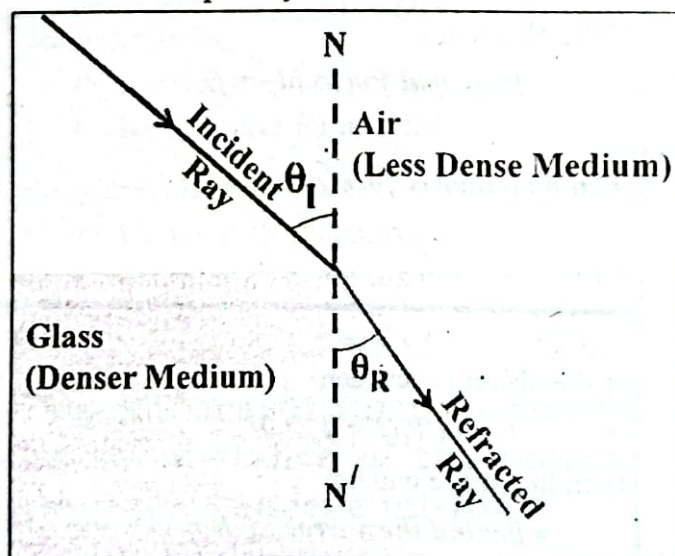
$\angle AON$ is the angle of incidence. It is the angle made by the incident ray with normal.

6. Angle of Reflection θ_R

$\angle BON'$ is the angle of refraction. It is the angle made by the refracted ray with normal.

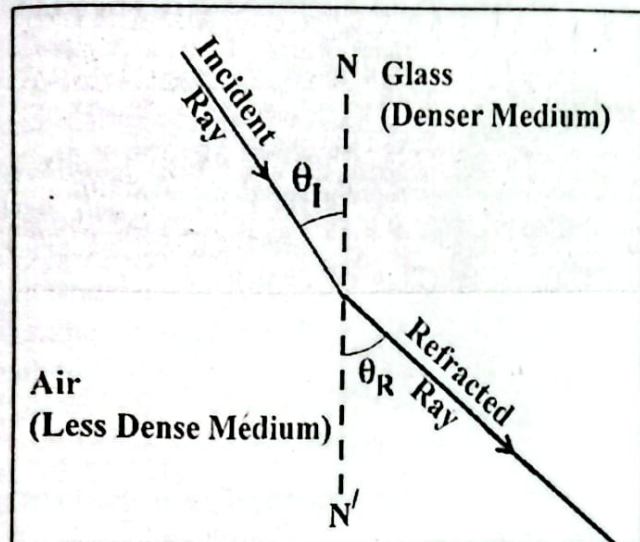
7. Optically Denser Medium

Medium having greater refraction effect is known as optically denser medium.



When light passes from optically less dense medium such as air into optically denser medium such as glass, it refracts towards the normal (i.e. $\theta_I > \theta_R$).

8. Optically Less Dense (Rarer) Medium



When light passes from optically denser medium such as glass into optically less dense medium, it refracts away the normal (i.e. $\theta_i < \theta_r$).

Refractive Index

The ratio of the speed of light in vacuum to the speed of light in a given medium is called refractive index of the medium.

i.e.
$$n = \frac{c}{v}$$

Where, 'n' is the index of refraction, 'c' is the speed of light in vacuum (3×10^8 m/s) and 'v' is the speed of light in the given medium. Refractive index has no unit.

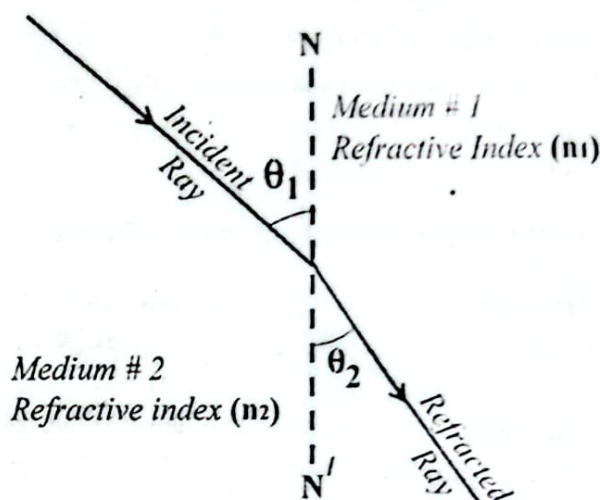
The speed of light in any material medium is always less than the speed of light in vacuum. So, the refractive index of any material medium is always greater than 1.

Snell's Law

The mathematical form of Snell's law is;

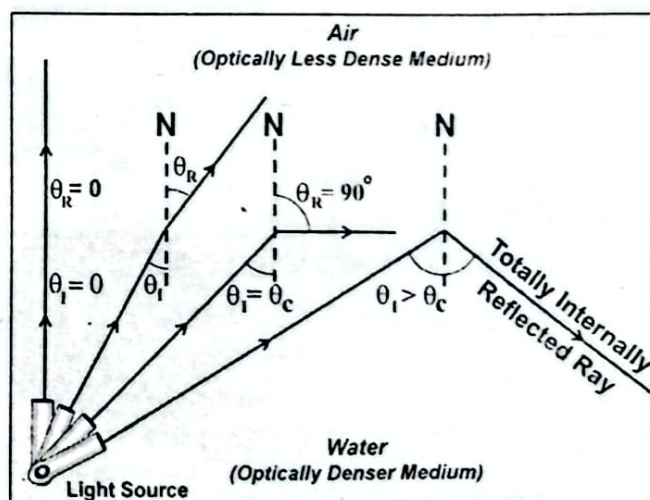
$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

Where, n_1 and n_2 are the refractive indices of medium # 1 and medium # 2, and θ_1 and θ_2 are the angles between the ray of light and normal in medium # 1 and medium #2, respectively, as shown in the figure.



Total Internal Reflection of Light

When light travels from an optically denser medium to a less dense medium and strikes the boundary at an angle greater than critical angle, the total light reflects back in the denser medium. This phenomenon is called total internal reflection.



As we know that angle of refraction is greater than angle of incidence when light passes from optically denser medium to a less dense medium.

In the figure, as we increase the angle of incidence, the angle of refraction also increases. At a certain angle of incidence the refracted ray becomes parallel to the boundary. This angle of incidence is called *critical angle* ' θ_c '.

When the angle of incidence is further increased (i.e. $\theta_i > \theta_c$), then all the light is reflected back in the optically denser medium. This phenomenon is called total internal reflection.

Conditions for Total Internal Reflection

- The light ray must be traveling from an optically denser medium to a less dense medium.
- The angle of incidence in the denser medium must be greater than critical angle of the denser medium.

Relationship between Critical angle and Refractive index of a medium.

Using Snell's law;

$$n_1 \sin \theta_1 = n_2 \sin \theta_2 \dots \dots \dots (1)$$

Here,

n_1 = refractive index of the denser medium

n_2 = refractive index of the less dense medium

$$\theta_1 = \theta_i = \theta_c$$

$$\theta_2 = \theta_r = 90^\circ$$

Now

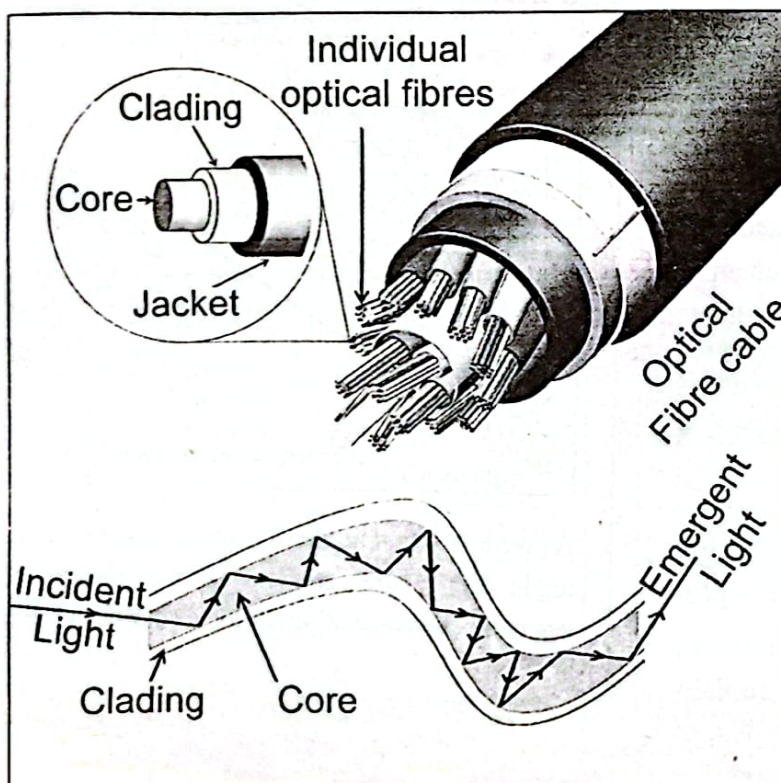
$$(1) \Rightarrow n_1 \sin \theta_c = n_2 \sin (90) \dots \dots \dots (2)$$

$$(2) \Rightarrow \sin \theta_c = \frac{n_2}{n_1} \quad [\because \sin (90) = 1]$$

The above equation shows that *the sine of critical angle is equal to the ratio of the refractive index of the refracting medium to the refractive index of the incident medium.*

Optical Fibres

Optical fibre is the most important application of total internal reflection. An optical fibre consists of three concentric cylindrical sections: the core, cladding and jacket. As shown in the figure, the light travelling through the fibre always hits the boundary between core and cladding at an angle greater than critical angle and totally reflected back in the core instead of transmitting through the boundary.



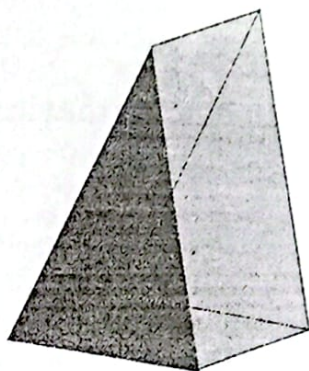
Core: The core is the innermost section composed of transparent glass or plastic having higher refractive index. The core acts as the denser incident medium for total internal reflection.

Cladding: The core is coated with a plastic / glass whose refractive index is smaller than that of the core called cladding. The cladding acts as the refracting medium for total internal refraction.

Jacket: The outermost layer is made of plastic called jacket. The jacket protects the fibre against moisture, abrasion, crushing and other environmental dangers.

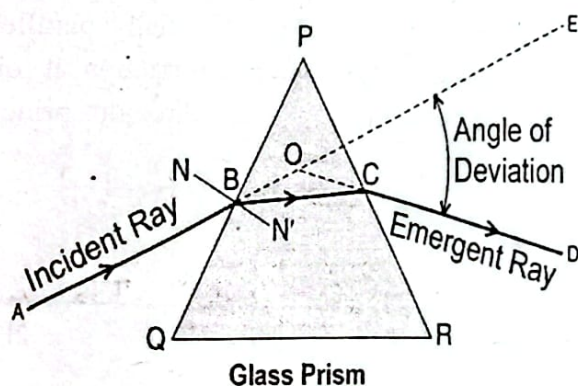
Refraction of light through Prism

A prism is made up of a transparent glass or plastic. It consists of two parallel triangular surfaces and three rectangular surface inclined with each other.



Deviation of light through Prism

When light ray enters from air into the prism, it bends towards the normal because the material of the prism has a higher refractive index than air.



When the light ray emerges into air on the other side, it bends away from the normal.

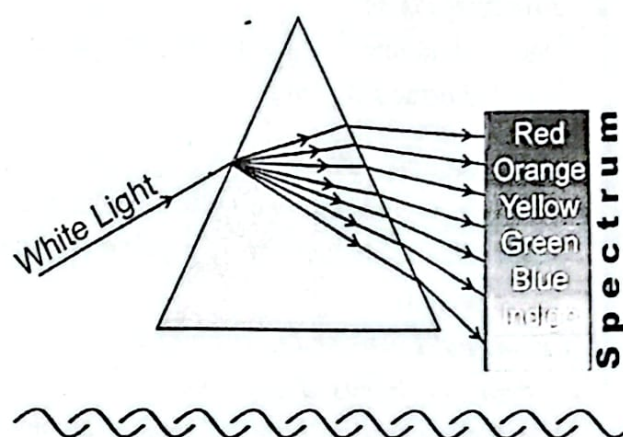
In the figure,

- Line $\overline{AB}$ represents the incident ray.
- Line $\overline{BC}$ represents the refracted ray.
- Line $\overline{CD}$ represents the emergent ray.
- $\angle ABN$ is the angle of incidence.
- $\angle CBN'$ is the angle of refraction.
- $\angle CEO$ is the angle of deviation.

As shown in the figure, the light ray bends when it passes through the prism. The amount of change in the direction of light is called *angle of deviation*. The angle of deviation is obtained by extending the incident ray in forward direction and the emergent ray in backward direction.

Dispersion of light through Prism

The splitting up of sunlight (white light) into a band of colors (spectrum) is called dispersion of light. Since sunlight (white light) is a mixture of many colors, when it pass through prism its colors separate because the refractive index of the material of the prism is different for different colors.



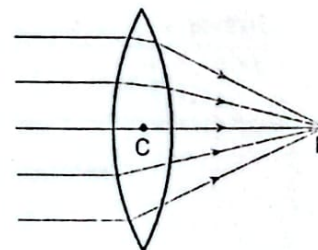
Lenses

A lens is a piece of transparent material (glass or plastic) that refracts light in a regular way.

Convex Lens

A lens that is thicker at the centre than the edges is called convex lens.

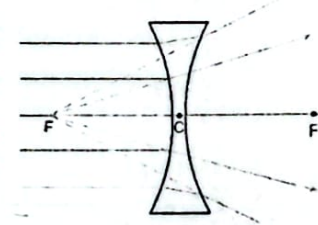
Convex lens is also called *converging lens* because it converges (focuses) a parallel beam of light after refraction.



Concave Lens

A lens that is thinner at the centre than the edges is called concave lens.

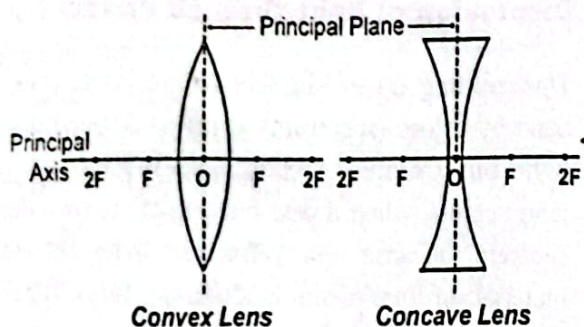
Concave lens is also called *diverging lens* because it diverges a parallel beam of light after refraction.



Terms Related to Lens

1. Optical Centre

The midpoint of a lens is called optical centre. It is denoted by 'O'.



2. Principal Plane

The vertical line passing through optical centre is called principal plane.

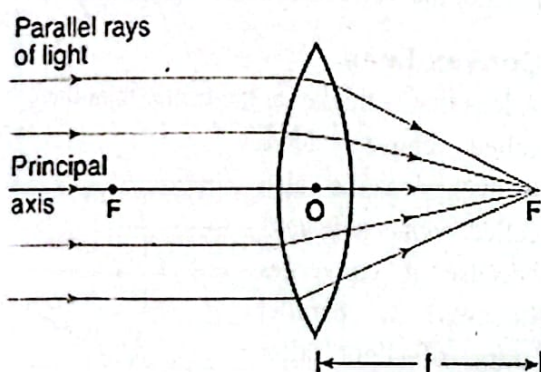
3. Principal axis

The line passing through optical centre and is perpendicular to the principal plane is called principal axis.

4. Principal Focus or Focal Point (F)

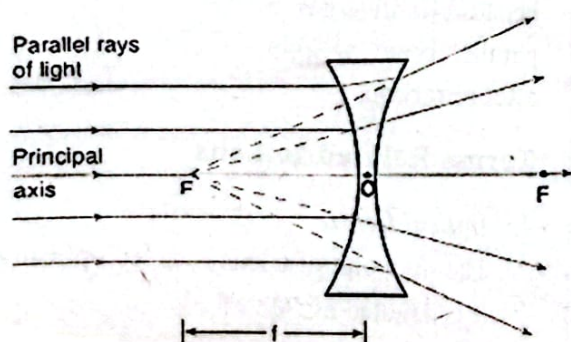
• Principal Focus of Convex lens

It is the point on principal axis of a convex lens at which a parallel beam of light focuses after refraction. A convex lens has two principal foci.



• Principal Focus of Concave lens

It is the point on principal axis of a concave lens from which a parallel beam of light appears to diverge after refraction. A concave lens has also two principal foci.



5. Focal Length

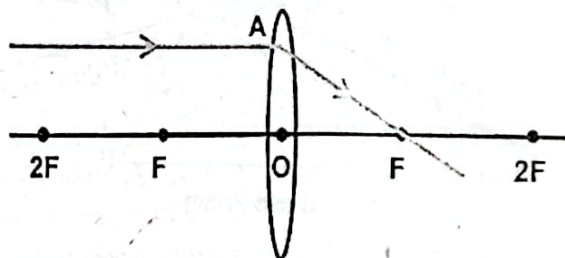
The distance between the principal focus and optical centre is called focal length of the lens.

Image formation and ray tracing for lenses

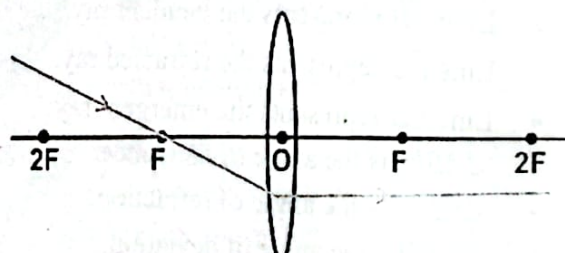
Following are the steps for drawing the ray diagram used to show image formation by a lens.

- Draw a lens and its principal axis showing focal point 'F' and '2F'.
- Draw the object such that its one end lies on the principal axis.
- Draw three special rays that arise from the tip of the object.

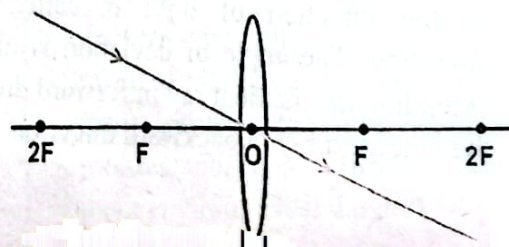
- A-Ray:** The A-Ray is initially parallel to principal axis and after refraction, it (or its extrapolation) passes through principal focus.



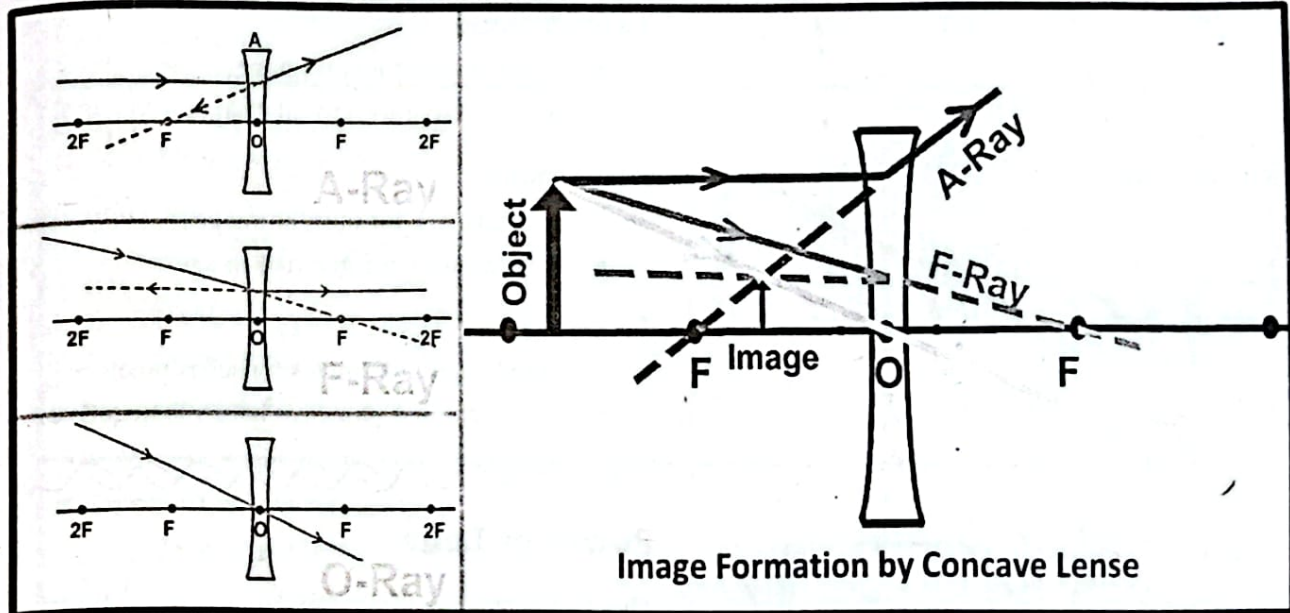
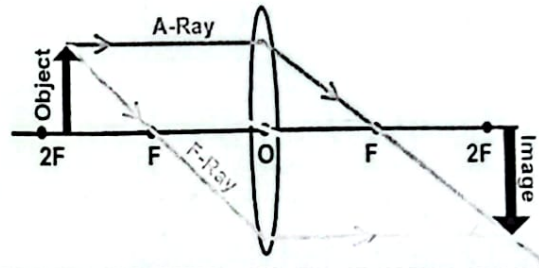
- F-Ray:** The F-Ray initially passes through principal focus and after refraction, it (or its extrapolation) passes parallel to principal axis.



- O-Ray:** The O-Ray passes straight through the optical center of the lens.



5. The point where all the rays (A-Ray, F-Ray and O-Ray) intersect each other is the image point.



The Lens Equation

The lens equation is a precise mathematical relationship between the object distance ' d_o ', the image distance ' d_i ' and focal length of the lens ' f '.

In the figure:

- f = the focal length of the lens
- h_o = the height of the object
- h_i = the height of the image
- d_o = the distance of object from the lens
- d_i = the distance of image from the lens

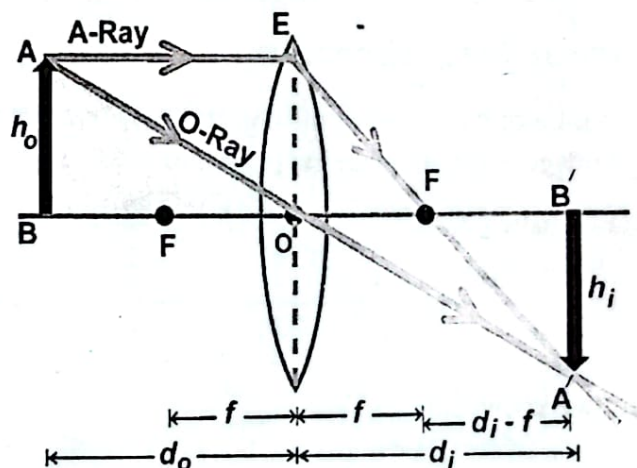
From the figure,

$$\Delta ABO \approx \Delta A'B'O$$

So,

$$\frac{AB}{A'B'} = \frac{BO}{B'O}$$

$$\Rightarrow \frac{h_o}{-h_i} = \frac{d_o}{d_i} \dots \dots \dots (1)$$



Again from the figure,

$$\Delta EOF \approx \Delta A'B'F$$

So,

$$\frac{EO}{A'B'} = \frac{OF}{B'F} \quad (\because EO = AB = h_o)$$

$$\Rightarrow \frac{h_o}{-h_i} = \frac{f}{d_i - f} \dots \dots \dots (2)$$

Comparing equations (1) and (2), we get

$$\frac{d_o}{d_i} = \frac{f}{d_i - f}$$

$$\Rightarrow d_i f = d_o (d_i - f)$$

$$\Rightarrow d_i f = d_o d_i - d_o f \dots\dots\dots(3)$$

Dividing both side by $d_o d_i f$

$$\Rightarrow \frac{\cancel{d_i} f}{d_o \cancel{d_i} f} = \frac{\cancel{d_o} \cancel{d_i}}{\cancel{d_o} \cancel{d_i} f} - \frac{\cancel{d_o} f}{\cancel{d_o} d_i f}$$

$$\Rightarrow \frac{1}{d_o} = \frac{1}{f} - \frac{1}{d_i}$$

$$\Rightarrow \frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \dots\dots\dots(4)$$

Equation (4) as known as the lens equation.

Linear Magnification

The ratio of the height of the object to height of the image is called linear magnification.

Mathematically;

$$M = \frac{h_i}{h_o} \dots\dots\dots(1)$$

But we know that

$$\begin{aligned} \frac{h_o}{h_i} &= -\frac{d_o}{d_i} \\ \Rightarrow \frac{h_i}{h_o} &= -\frac{d_i}{d_o} \dots\dots\dots(2) \end{aligned}$$

Equation (1) can be written as

$$M = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

Convention for Lens Equation

The following sign convention has been established for both convex and concave lenses.

Object distance:

- d_o is always positive.

Image distance:

- d_i is positive for real images.
- d_i is negative for virtual images.

Image attitude:

- h_i is positive for upright images.
- h_i is negative for inverted images.

Focal length:

- Focal length of convex lenses is positive.
- Focal length of concave lenses is negative.

Power of Lens

The degree of convergence or divergence of light rays by a lens is known as power of lens.

Mathematically;

$$D = \frac{1}{f}$$

Where f is the focal length of the lens expressed in meter. The unit of power of lens is 'dioptre'.

Dependence of Image's Features on the distance of the object ' d_o ' form the Convex Lens

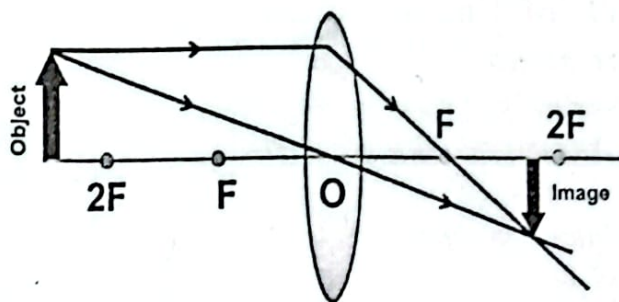
The features of the image (*magnification, attitude, location and type*) depends on the distance of the object from the lens.

If the object is beyond

$2F$ (i.e. $d_o > 2f$)

then the image will be:

- between $2F$ and F (i.e. $2f > d_i > f$)
- real
- smaller than object
- inverted

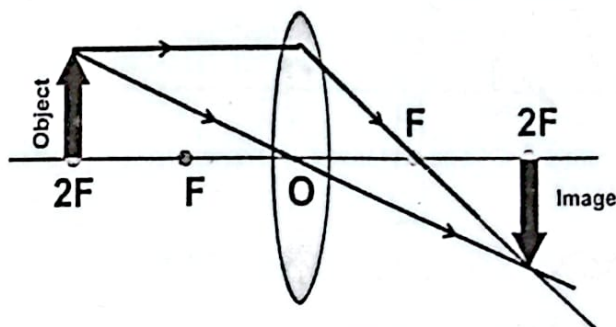


If the object is at

$2F$ ($d_o = 2f$)

then the image will be:

- at $2F$ ($d_i = 2f$)
- real
- same size
- inverted

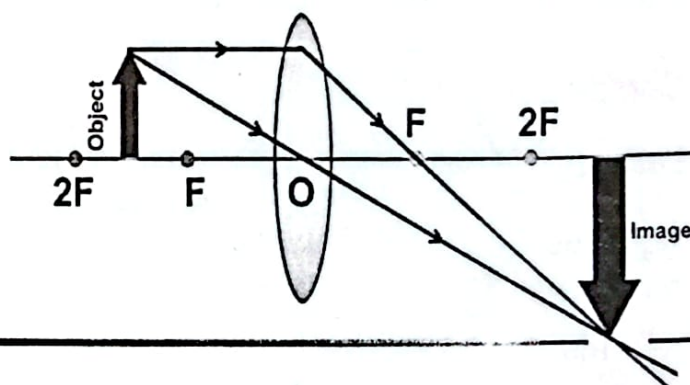


If the object is between

$2F$ and F ($2f > d_o > f$)

then the image will be:

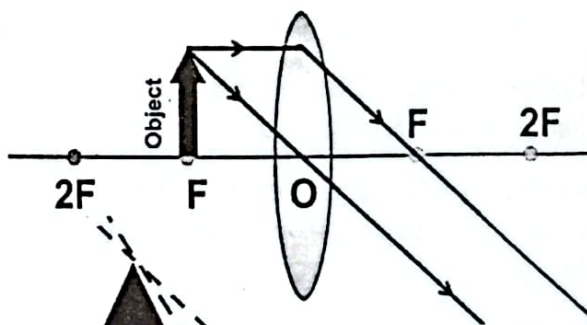
- beyond $2F$ ($d_i > 2f$)
- real
- larger than object
- inverted



If the object at

Principal Focus ($d_o = f$)

then no image is formed at all.

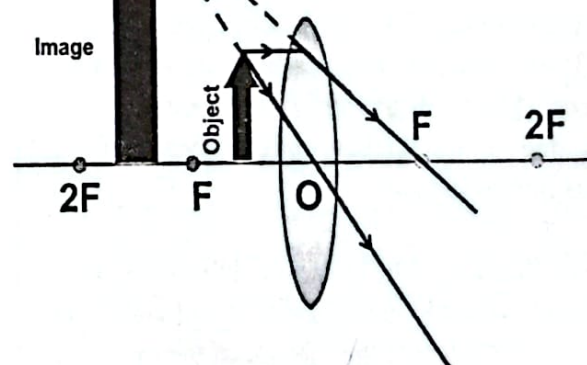


If the object is between

F and O ($f > d_o > 0$)

then the image will be:

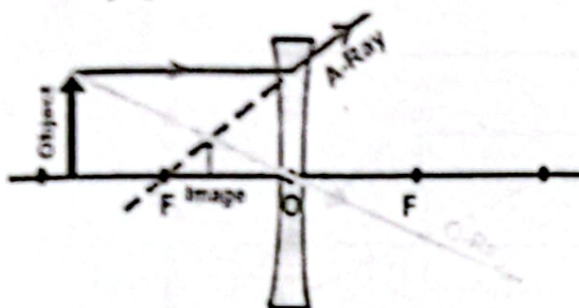
- at the same side (d_i is negative)
- virtual
- highly Magnified
- upright



Features of Image Formed by a Concave Lens

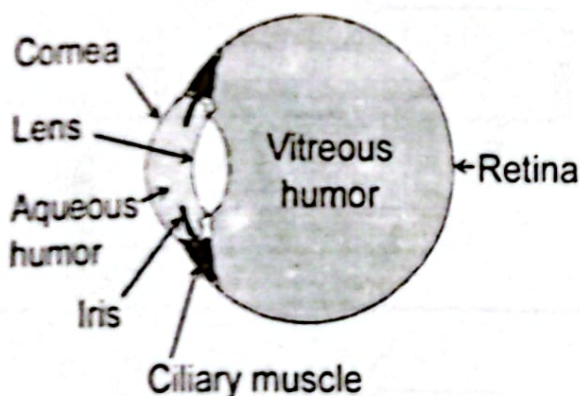
The image formed by a concave lens is always:

- At the same side (d_i is negative)
- Virtual
- Smaller than object
- Upright



Human Eye

The following is a diagram of human eye.



Every part of the human eye has its own function. The parts and terms are briefly described below.

1. **Cornea:** Cornea is the transparent front part of the eye that covers pupil, iris. It allows light to enter the eye.
2. **Aqueous Humor:** The aqueous humor is a transparent watery fluid with refractive index of 1.336. It fills the chamber between cornea and lens. Most of the refraction occurs at cornea due to the higher optical density of aqueous humor than air.
3. **Vitreous Humor:** The vitreous humor is a transparent gel-like substance with refractive index $n = 1.337$. It fills the interior of the eye.

4. **Retina:** The retina is on the curved back surface of the eye ball. It is composed of many nerves which change the light energy into electrical signals. These electrical signals travel in the optical nerves to the brain for interpretation.

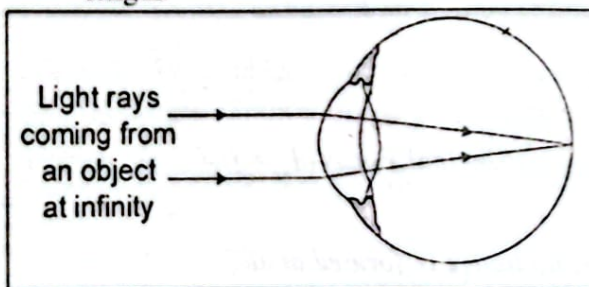
5. **Iris:** The iris is a flat and ring-shaped colored membrane behind the cornea which acts as curtain for the lens. It adjust automatically to control the amount of light entering the eye.

6. **Lens:** The lens of the eye has refractive index equals to 1.386 – 1.406. It acts as a fine adjustment for focusing at different distances.

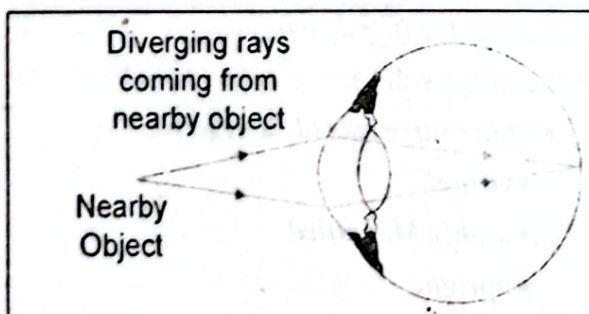
7. **Ciliary muscle:** Ciliary muscle change the curvature (and hence the focal length) of the lens for focusing at different distances.

8. **Accommodation:** The term accommodation is used for the focusing adjustment of the eye lens.

- To focus (or accommodate) a distant object, the ciliary muscles are relaxed and the lens becomes thin, thus increasing the focal length.



- To focus (or accommodate) a nearby object, the ciliary muscles contract and the lens becomes thick, thus shortening the focal length.



9. **Near Point:** The closest distance at which the eye can focus (or accommodates) clearly is called the near point of the eye. For a normal eye, it is typically 25 cm which increases with age.

10. **Far Point:** The farthest distance at which eye can focus (or accommodates) clearly is called the far point of the eye. Since we can focus on moon and stars, so the far point is infinity.

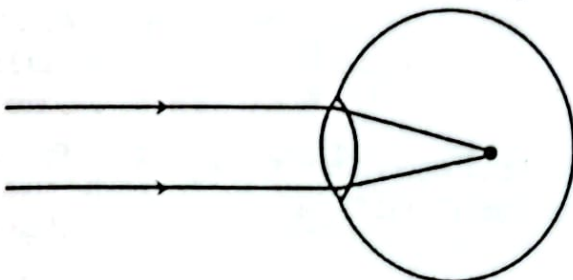
Short-Sightedness (Myopia)

A person suffering from short sightedness can see nearby objects clearly while cannot see distant objects clearly.

Causes:

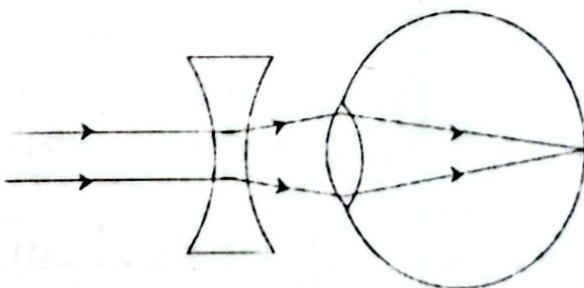
- Either the eyeball is too long.
- Or the power of lens is too high.

In either case, the image of the distant objects are focused in front of retina as shown in the figure.



Object at Far Point

Correction: A concave (diverging) lens of appropriate power is used. The diverging lens diverge the parallel rays coming from the far object such that they are focused on retina, as shown in the figure.



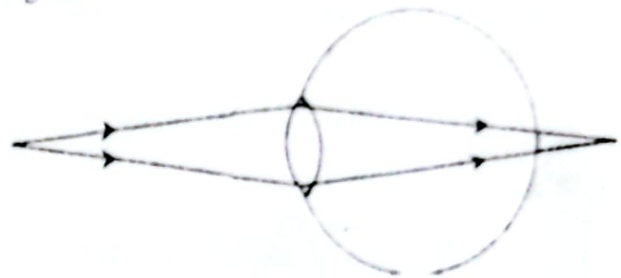
Long-Sightedness (Hyperopia)

A person suffering from long sightedness can see distant objects clearly while cannot see nearby objects clearly.

Causes:

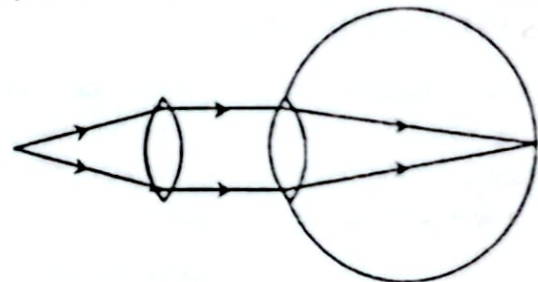
- Either the eyeball is too short.
- Or the power of lens is too low.

In either case, the image of the nearby objects is focused in behind the retina as shown in the figure.



Object at Near Point

Correction: A convex (converging) lens of appropriate lens is used in case of long sightedness. The converging lens converges the light rays coming from a nearby object such that they are focused on retina as shown in the figure.



Resolving Power

The term resolution (resolving power) is used in optics which means the capacity of an instrument to distinctively separate two points which are close together.

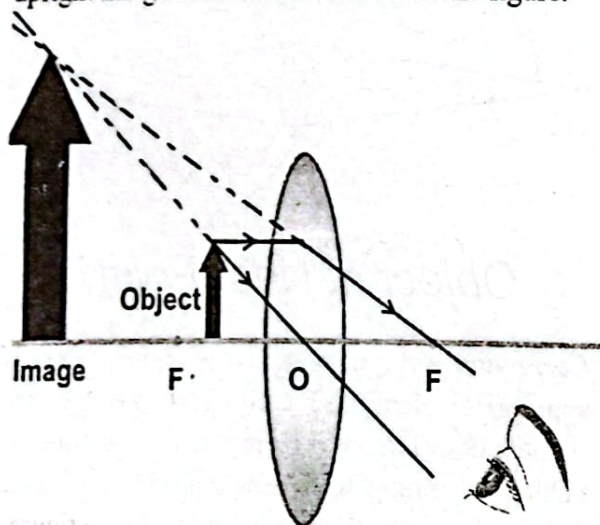
For example, the two headlights of a distant car appear as single head light which is the unresolved image of the two headlights. When the car continues to approach, the separation between the headlights increases. Finally the individual headlight can be seen clearly. Now it is the

resolved image of the headlights because they are seen distinctively separated from each other.

Simple Microscope (Magnifying Glass)

A simple microscope is just a convex lens which produces relatively larger image small or distant objects.

The simple microscope works on the principle that when an object is placed within the focal length of a convex lens, a highly magnified, virtual and upright image is formed as shown in the figure.



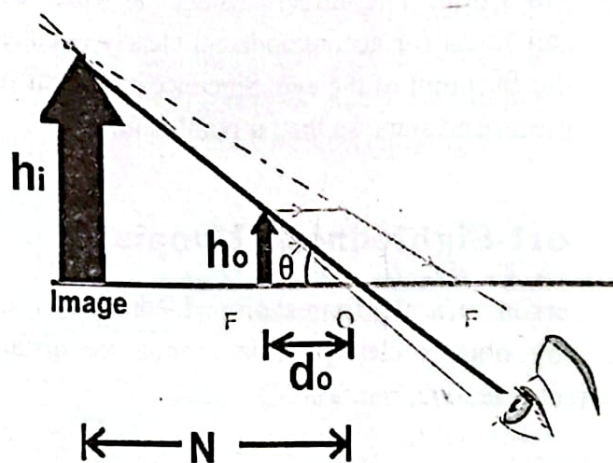
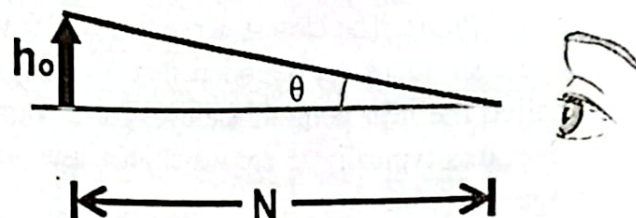
Angular Magnification

Angular magnification ' m_θ ' is the ratio of the angular size ' θ' ' of the final image formed by the instrument to the reference angular size ' θ ' of the object seen without the instrument.

$$\text{i.e. } m_\theta = \frac{\text{Angular size of the final image produced by the instrument}}{\text{Reference angular size of object seen without the instrument}}$$

$$\text{or } m_\theta = \frac{\theta'}{\theta} \quad \text{.....(1)}$$

Consider the following diagram which shows both the cases: (1) the reference angular size ' θ ' of the object seen without an optical instrument and (2) the angular size ' θ' ' of the final image produced by the simple microscope.



From the figure,

$$\tan \theta = \frac{h_o}{N} \quad \text{.....(2)}$$

$$\tan \theta' = \frac{h_i}{N} = \frac{h_o}{d_o} \quad \text{.....(3)}$$

For small angles $\tan \theta = \theta$ and $\tan \theta' = \theta'$. So, equations (2) and (3) become

$$(2) \Rightarrow \theta = \frac{h_o}{N} \quad \text{.....(4)}$$

$$(3) \Rightarrow \theta' = \frac{h_o}{d_o} \quad \text{.....(5)}$$

Put the values in equation (1),

$$(1) \Rightarrow m_\theta = \frac{h_o/d_o}{h_o/N} \quad \text{.....(4)}$$

$$\Rightarrow m_\theta = \frac{h_o}{d_o} \times \frac{N}{h_o}$$

$$\Rightarrow m_\theta = \frac{N}{d_o} = \left(\frac{1}{d_o} \right) N \quad \text{.....(5)}$$

As we know that

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$\Rightarrow \frac{1}{d_o} = \frac{1}{f} - \frac{1}{d_i} \dots \dots \dots (6)$$

Put equation (6) in equation (5)

$$(5) \Rightarrow m_o = \left(\frac{1}{f} - \frac{1}{d_i} \right) N \dots \dots \dots (7)$$

For the image at near point $d_i = -N$ (minus sign indicates the virtual image) and equation (7) becomes

$$(7) \Rightarrow m_o = \left(\frac{1}{f} - \frac{1}{-N} \right) N$$

$$\Rightarrow m_o = \left(\frac{1}{f} + \frac{1}{N} \right) N = \frac{N}{f} + \frac{N}{N}$$

$$\Rightarrow m_o = \frac{N}{f} + 1 \dots \dots \dots (8)$$

For the image at far point $d_i = \infty$ and equation (7) becomes

$$(7) \Rightarrow m_o = \left(\frac{1}{f} - \frac{1}{\infty} \right) N$$

$$\Rightarrow m_o = \left(\frac{1}{f} + 0 \right) N \quad \left(\because \frac{1}{\infty} = 0 \right)$$

$$\Rightarrow m_o = \frac{N}{f} \dots \dots \dots (9)$$

Compound Microscope

A compound microscope consists of two converging lenses i.e. eye piece and objective.

- The **objective** has smaller aperture and focal length that provides a real image to the eye piece.
- The **eye piece** has larger aperture and focal length that acts as magnifying glass. It magnifies the real image formed by objective.

The object to be examined is placed just beyond the principal focus..

Magnification

As we know that

$$M = \frac{\text{size of the final image}}{\text{size of the object}}$$

$$\Rightarrow M = \frac{A''B''}{AB} \dots \dots \dots (1)$$

Dividing numerator and denominator of equation (1) by $A'B'$

$$(1) \Rightarrow M = \frac{A''B''/A'B'}{AB/A'B'}$$

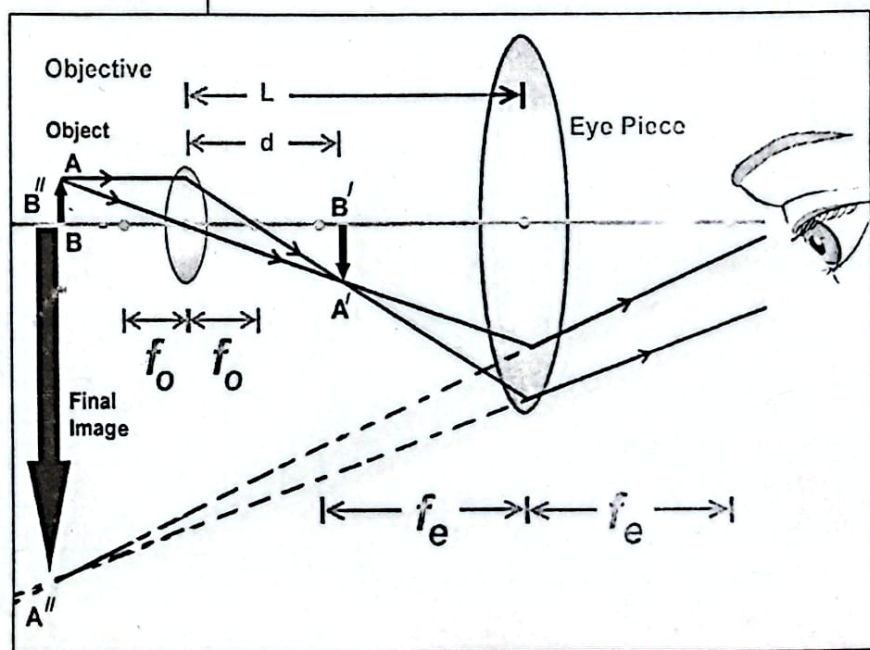
$$\Rightarrow M = \frac{A''B''}{A'B'} \div \frac{AB}{A'B'} = \frac{A''B''}{A'B'} \times \frac{A'B'}{AB}$$

$$\Rightarrow M = M_e \times M_o \dots \dots \dots (2)$$

$$\text{Here, } M_e = \frac{N}{f_e} \quad \text{and} \quad M_o = -\frac{d_i}{d_o} = -\frac{d_i}{f_o}$$

$$(2) \Rightarrow M = -\frac{d_i}{f_o} \times \frac{N}{f_e} \dots \dots \dots (3)$$

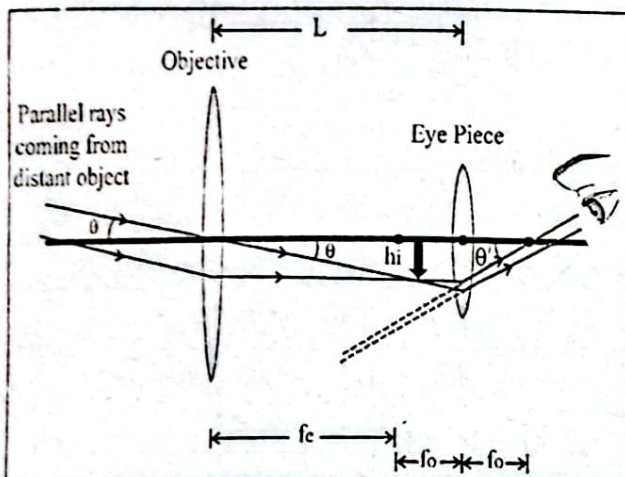
The minus sign indicates that the final image is inverted.



Refracting Telescope

A telescope is used for magnifying distant objects such as stars and planets. It consists of two converging lenses: eye piece and objective.

- The objective has larger aperture and focal length. It produces a real image of the distant object.
- The eye piece has smaller aperture and focal length than objective. It magnifies the real image produced by the objective.



Magnification:

As we know that

$$m_o = \frac{\theta'}{\theta} \dots \dots \dots (1)$$

From the figure,

$$\theta = -\frac{h_i}{f_o} \dots \dots \dots (2)$$

and $\theta' = \frac{h_i}{f_e} \dots \dots \dots (3)$

Putting equations (2) and (3) in equation (1),

$$m_o = \frac{h_i}{f_e} \div \left(-\frac{h_i}{f_o} \right) \Rightarrow m_o = -\frac{f_o}{f_e} \dots \dots \dots (4)$$

EXERCISE

Multiple Choice Questions

- If the angle of incidence is 30° the angle of reflection will be

A 30°	B 45°
C 90°	D 210°
- When r is the radius of curvature of concave mirror, real diminished image will be formed when the object is at

A $d_o > r$	B $d_o = r$
C $r > d_o > f$	D $d_o = f$
- The focal length of convex mirror with radius of curvature 10 cm is

A +10 cm	B -5 cm
C -10 cm	D -5 cm
- An object is placed 7 cm from a concave mirror whose radius of curvature is 10 cm, the image formed will be

A Real & upright	B Virtual & upright
C Real & inverted	D Virtual & inverted
- Which one of the following materials will refract light more

A Water	B Glass
C Air	D Diamond
- A convex lens with focal length 8.00 cm has the power of lens

A 2.05 D	B 4.00 D
C 12.5 D	D 16.0 D
- If the distance from your eye's lens to the retina is shorter than for normal eye, you will struggle to see objects that are

A Nearby	B Colorful
C Far away	D Moving fast
- Who benefits more from using magnifying glass, a person whose near point is located at a distance away from the eyes of

A 75 cm	B 50 cm
C 35 cm	D 25 cm
- The human eye forms the image of an object at its

A Iris	B Retina
C Pupil	D Cornea

Conceptual Questions

1. Which type of lens would you use to start fire from light from sun concave or convex, would work best? At what distance from the lens should the paper be held for best results?

Ans. A convex lens will be used to start fire, because it focuses the parallel sun rays to a single point. Thus the energy spread over the surface of lens is concentrated at one point on the paper. As a result, the paper catches fire. The lens should be held at a distance equal to its focal length for best results.

If a concave mirror produces a real image, is the image necessarily inverted? Explain.

Ans. Yes, the real image formed by a concave mirror will always be inverted.

A concave mirror can produce both real and virtual images while plane mirror and convex mirror produce only virtual images. A concave mirror produces real image only if the object is placed away from the focal point (F). The real image is always inverted because the concave mirror focuses the light rays at the point where the image is formed.

3. Are rearview mirrors used in cars concave or convex?

Ans. The rearview mirrors used in cars are convex mirrors because they provide a larger field of view (i.e. more image can fit onto the mirror) as compared to concave mirrors. Furthermore, the convex mirrors give erect images of the objects behind the driver.

4. A magician during a show makes a glass lens with $n = 1.47$ disappear in a trough of liquid. What is the refractive index of the liquid? Could the liquid be water?

Ans. A transparent material such as glass can be seen because it bends (refracts) the light rays passing through it. In other words, it has different refractive index than the surrounding.

In the present case, the magician inserts the glass lens in a liquid that has the same refractive index (i.e. $n = 1.47$) as that of the lens. As a result, no refraction occurs at the boundary of the lens and it disappears. Since the refractive index of water is 1.33, so water cannot be the liquid

5. Suppose that you were handed a lens and a ruler and told to determine the focal length of the lens. How would you proceed?

Ans. The focal length of the lens can be found by focusing the sunlight on a point (called focal point) and measuring the distance between the lens and the focal point with the help of ruler.

6. Can we achieve total internal reflection from optically rare medium to optically dense medium?

Ans. No, we cannot achieve total internal reflection from optically rare medium to optically dense medium. Because total internal reflection occurs only when light is traveling from optically dense medium to optically rare medium, which is one of the two fundamental conditions for total internal reflection.

7. Will a nearsighted person who wears corrective lenses in her glasses be able to see clearly underwater when wearing those glasses?

Ans. Near sightedness is caused when the eye ball bends the light too much and focuses it in front of retina. This bending of light occurs due to the difference in refractive indices of air and aqueous humor in the eyeball.

Since water has greater refractive index than air, therefore, no significant bending will occur when the near-sighted person is underwater and the person will become almost normal. But, if she is wearing corrective lenses in her glass, she will not be able to see clearly under water because in such a case she will become far-sighted due to very small bending of light and focusing of light behind retina.



8. When you use simple magnifying glass, does it matter whether you hold the object to be examined closer to the lens than its focal length or farther away? Explain.

Ans. A magnifying glass has a convex lens and is used to produce a magnified, virtual and erect image of the object. For this purpose the object must be placed within the focal length of the lens. So it matters whether we hold the object to be examined closer to the lens than its focal length or farther away.



9. In blind turns on hilly roads, mirrors are used to help drivers. Are these mirrors plane mirrors, concave mirrors or convex mirrors? Explain.

Ans. Mirrors are installed in blind turns for safety purposes to help drivers to prevent collisions. These mirrors are convex mirrors because they provide a wider angle of vision and larger field of view (i.e. more image can fit onto the mirror). Furthermore, they produce erect images of the objects.



Numerical Questions

1. A 1.50 cm high object is placed 20.0 cm from a concave mirror with radius of curvature 30.0 cm. Determine (a) the position of the image, and (b) its size, also draw the ray diagrams.

Given data :

Size of object ' h_o ' = 1.50 cm

Distance of object ' d_o ' = 20.0 cm

Radius of curvature ' r ' = 30.0 cm

Focal length ' f ' = $\frac{r}{2} = \frac{30.0}{2} = 15.0$ cm

Required:

- a) Distance of the image ' d_i ' = ?
b) Size of image ' h_i ' = ?

Solution :

- a) As we know that

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$\Rightarrow \frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o} \quad (\text{Put the values})$$

$$\frac{1}{d_i} = \frac{1}{15} - \frac{1}{20} = \frac{4-3}{60} = \frac{1}{60}$$

$$d_i = 60 \text{ cm}$$

- b) We also know that

$$\frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

$$h_i = -\frac{d_i}{d_o} \times h_o \quad (\text{Put the values})$$

$$h_i = -\frac{60}{20} \times 1.5$$

$$h_i = -4.5 \text{ cm}$$



2. A candle of height 8.0 cm is located at a distance of 300 mm from a convex mirror, its virtual image is formed behind the mirror at a distance of 3.0 cm from the pole (or vertex).

Find the focal length of the mirror and height of the image formed.

Given data :

Height of candle ' h_i ' = 8.0 cm

Distance of candle ' d_o ' = 300 mm
= 30.0 cm

Distance of image ' d_i ' = -3.0 cm
(virtual image)

Required :

a) Focal length ' f ' = ?

b) Height of image ' h_i ' = ?

Solution :

a) As we know that

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \quad (\text{Put the values})$$

$$\Rightarrow \frac{1}{f} = \frac{1}{30} + \frac{1}{-3}$$

$$\Rightarrow \frac{1}{f} = \frac{1+(-10)}{30}$$

$$\Rightarrow \frac{1}{f} = \frac{1-10}{30}$$

$$\Rightarrow \frac{1}{f} = -\frac{9}{30}$$

$$\Rightarrow f = -\frac{30}{9}$$

$$\Rightarrow f = -3.33 \text{ cm}$$

a) As we know that

$$\frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

$$\Rightarrow h_i = -\frac{d_i}{d_o} \times h_o \quad (\text{Put the values})$$

$$\Rightarrow h_i = -\frac{3}{30} \times 8$$

$$\Rightarrow h_i = -0.8 \text{ cm}$$



3. Calculate the speed of light in zircon with index of refraction $n=1.923$, a material used in jewelry to replicate diamond.

Given data :

Refractive index of zircon ' n ' = 1.923

Speed of light in vacuum ' c ' = $3 \times 10^8 \text{ m/s}$

Required :

Speed of light in zircon ' v ' =

Solution :

As we know that

$$n = \frac{c}{v}$$

$$\Rightarrow v = \frac{c}{n} \quad (\text{Put the values})$$

$$\Rightarrow v = \frac{3 \times 10^8}{1.923}$$

$$\Rightarrow v = 1.56 \times 10^8 \text{ m/s}$$



4. A light ray strikes an air-water surface at an angle of 46° with respect to the normal. The refractive index of water is 1.33. Find the angle of refraction when the direction of the ray is (a) from air to water and (b) from water to air.

Given data :

Angle of incidence ' θ_i ' = 46°

Refractive index of air ' n_1 ' = $1.000271 \approx 1$

Refractive index of water ' n_2 ' = 1.33

Required :

a) Angle of refraction ' θ_R ' = ?

(from air to water)

a) Angle of refraction ' θ_R ' = ?

(from water to air)

Solution :

a) **From air to water**

Using Snell's Law

$$n_1 \sin \theta_1 = n_2 \sin \theta_2 \dots \dots \dots (1)$$

In this case, $\theta_1 = \theta_i = 46^\circ$

and $\theta_2 = \theta_R = ?$

$$(1) \Rightarrow 1 \times \sin(46) = 1.33 \times \sin \theta_R$$

$$\Rightarrow \sin \theta_R = \frac{\sin(46)}{1.33}$$

$$\sin \theta_R = \frac{0.72}{1.33}$$

$$\theta_R = \sin^{-1}\left(\frac{0.72}{1.33}\right)$$

$$\theta_R = 33^\circ$$

b) From water to air

Using Snell's Law

$$n_1 \sin \theta_1 = n_2 \sin \theta_2 \dots \dots \dots (1)$$

In this case, $\theta_2 = \theta_1 = 46^\circ$

and $\theta_1 = \theta_R = ?$

$$(1) \Rightarrow 1 \times \sin \theta_R = 1.33 \times \sin(46)$$

$$\Rightarrow \sin \theta_R = 1.33 \times \sin(46)$$

$$\sin \theta_R = 1.33 \times 0.72$$

$$\theta_R = \sin^{-1}(0.96)$$

$$\theta_R = 74^\circ$$



5. An optical fibre is made from flint glass with index of refraction 1.66 and is surrounded by a cladding made of crown glass with index of refraction 1.52. what is the critical angle?

Given data :

Refractive index of core ' n_1 ' = 1.66

Refractive index of cladding ' n_2 ' = 1.52

Required :

Critical angle ' θ_c ' = ?

Solution :

As we know that

$$\sin \theta_c = \frac{n_2}{n_1} \quad (\text{Put the values})$$

$$\sin \theta_c = \frac{1.52}{1.66}$$

$$\Rightarrow \theta_c = \sin^{-1}(0.92)$$

$$\theta_c = 66.3^\circ$$

6. Suppose the book page is held 7.50 cm from a convex lens of focal length 10.0 cm and concave lens of focal length -10 cm. what magnification is produced in each case?

Given data :

Distance of the newspaper ' d_o ' = 7.5 cm

Focal length of the convex lens ' f ' = +10 m

Focal length of the concave lens ' f ' = -10 m

Required :

a) Magnification of Image by convex lens ' M ' = ?

b) Magnification of Image by concave lens ' M ' = ?

Solution :

a) For Convex Lens

As we know that

$$M = -\frac{d_i}{d_o} \dots \dots \dots (1)$$

We also know that

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$\Rightarrow \frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o} \quad (\text{Put the values})$$

$$\frac{1}{d_i} = \frac{1}{10} - \frac{1}{7.5}$$

$$\frac{1}{d_i} = \frac{7.5 - 10}{75} = \frac{-2.5}{75}$$

$$d_i = -\frac{75}{2.5} = -30 \text{ cm}$$

Putting the values in equ. (1)

$$(1) \Rightarrow M = -\frac{-30}{7.5}$$

$$M = 4$$

b) For Concave Lens

As we know that

$$M = -\frac{d_i}{d_o} \dots \dots \dots (2)$$

We also know that

$$\frac{1}{f^-} = \frac{1}{d_o^-} + \frac{1}{d_i^-}$$

$$\Rightarrow \frac{1}{d_i^-} = \frac{1}{f^-} - \frac{1}{d_o^-} \quad (\text{Put the values})$$

$$\frac{1}{d_i^-} = \frac{1}{-10} - \frac{1}{7.5}$$

$$\frac{1}{d_i^-} = \frac{-7.5 - 10}{75} = \frac{17.5}{75}$$

$$d_i^- = -\frac{75}{17.5} = -4.3 \text{ cm}$$

Putting the values in equ. (2)

$$(2) \Rightarrow M^- = -\frac{4.3}{7.5}$$

$$M^- = 0.57$$



7. Gulalai is viewing a flea using a magnifier with $f = 3.0 \text{ cm}$. If her near point is at $N = 25 \text{ cm}$ then calculate the maximum magnification she can get.

Given data :

Focal length ' f ' = 3.0 cm

Near point ' N ' = 25 cm

Required:

Maximum magnification ' m_o ' = ?

Solution :

a) As we know that

$$m_o = \frac{N}{f} + 1 \quad (\text{Put the values})$$

$$m_o = \frac{25}{3} + 1$$

$$m_o = 8.33 + 1$$

$$m_o = 9.33$$



8. A telescope has a magnification of 40.0 and a length of 1230 mm. what are the focal lengths of the objective and eyepiece?

Given data :

Magnification ' m_o ' = 40.0

Length ' L ' = $1230 \text{ mm} = 123 \text{ cm}$

Required:

a) Focal length of objective ' f_o ' = ?

b) Focal length of eyepiece ' f_e ' = ?

Solution :

As we know that

$$m_o = \frac{f_o}{f_e}$$

$$\Rightarrow \frac{f_o}{f_e} = 40.0 \dots\dots\dots (1)$$

We also know that

$$L = f_o + f_e$$

$$\Rightarrow f_o + f_e = 123 \text{ cm}$$

$$\Rightarrow f_o = 123 - f_e \quad (\text{put the values in equ. 1})$$

$$(1) \Rightarrow \frac{123 - f_e}{f_e} = 40.0$$

$$\Rightarrow \frac{123}{f_e} - \frac{f_e}{f_e} = 40.0$$

$$\frac{123}{f_e} - 1 = 40.0$$

$$\frac{123}{f_e} = 40.0 + 1$$

$$\frac{123}{f_e} = 41$$

$$123 = 41 f_e$$

$$\text{or } f_e = \frac{123}{41}$$

$$\text{or } f_e = 3 \text{ cm}$$

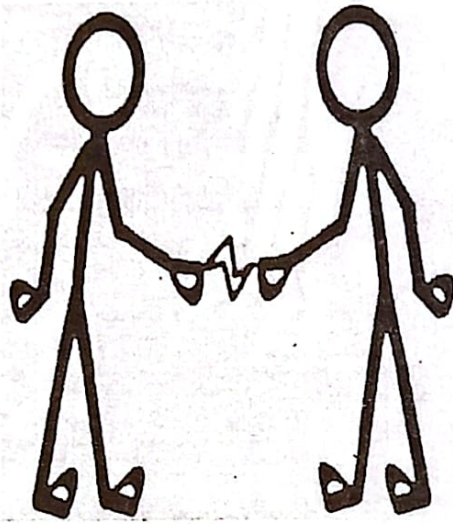
(Put the value of f_e in equ. 1)

$$(1) \Rightarrow \frac{f_o}{3} = 40.0$$

$$\text{or } f_o = 40 \times 3$$

$$\text{or } f_o = 120 \text{ cm}$$





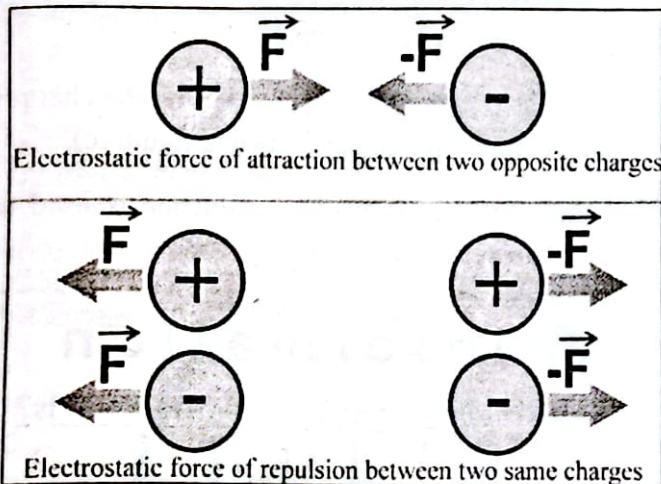
UNIT 13
ELECTROSTATICS

Electrostatics

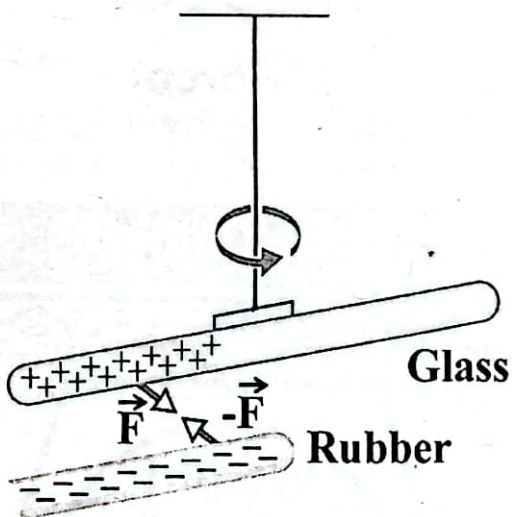
The branch of physics which deals with the study of static charges is called electrostatics.

Electric Charge

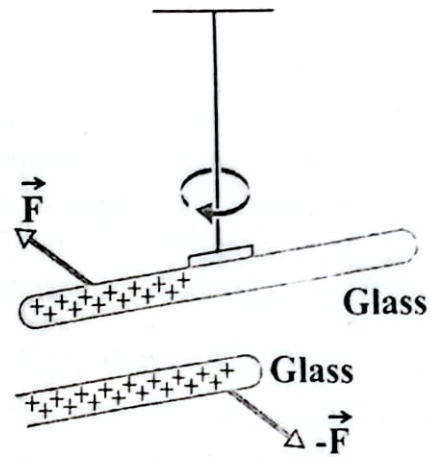
The electric charge is a property of elementary particles due to which same charges repel each other while opposite charges attract each other.



The SI unit of charge is coulomb 'C'. There are two types of charges (i.e. positive charge and negative charge) as illustrated in the following activity.



when a rubber rod rubbed with fur is brought near to a suspended glass rod rubbed with silk, we will observe that they attract each other.

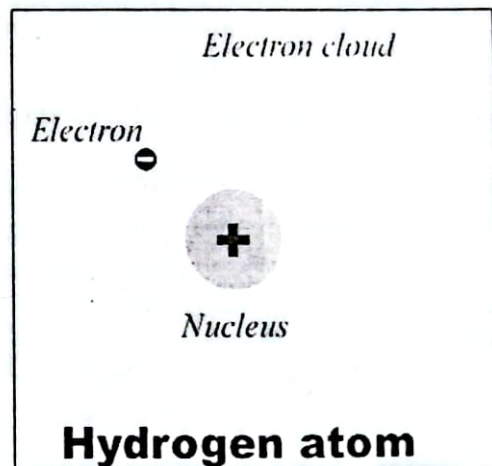


Now, when a glass rod rubbed with silk is brought near to another suspended glass rod rubbed with silk, we will observe that they repel each other.

From these observations, it is concluded that there are two types of charges and like charges repel while unlike charges attract each other.

Elementary Charge:

As we know that atoms have two kinds of charges i.e. positive charge on protons and negative charge on electrons. The protons along with neutrons (neutral particles) are contained in the nucleus and the electrons revolve around the nucleus.



The charge on an electron or proton is termed as elementary (or fundamental) charge 'e'. The total charge on a body is always equal to the integral multiple of the elementary charge.

i.e. $Q = ne$

Where, 'Q' is charge on the body, 'e' is the elementary charge and $n = 1, 2, 3, \dots$

Neutral Objects:

Every material object is made of atoms, thus having charges in it. But we often cannot notice the effects of the charges because the atoms of these objects have same number of protons and electrons. As a result, the net effect is zero and these objects are electrically neutral.

Charged Objects (Electrified Objects):

When we electrify (or charge) an object, it means that some charge is transferred to the object. For example, when we rub one object with another, some charges (electrons) are transferred from one object to the other.

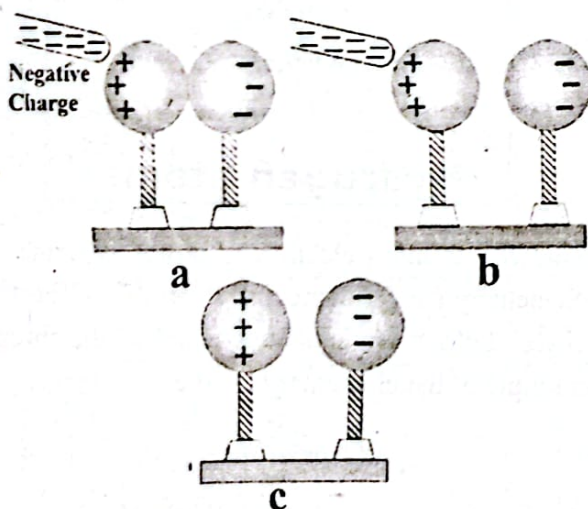
- The object that gains electrons gets negative charge.
- The object that loses electrons gets positive charge.

The process of charging an object electrically by addition or removal of charges (specifically electrons) is called *electrification*.

Electrostatic Induction

The modification in the distribution of charges in a body caused by the influence of a nearby charged body is called electrostatic induction.

Consider two insulated metallic spheres 'A' and 'B' as shown in the figure.



Firstly, the metal spheres touch each other and a negatively charged rubber strip is brought near to sphere 'A' as shown in figure (a). The electrons in the spheres are repelled to the far side in sphere 'B'.

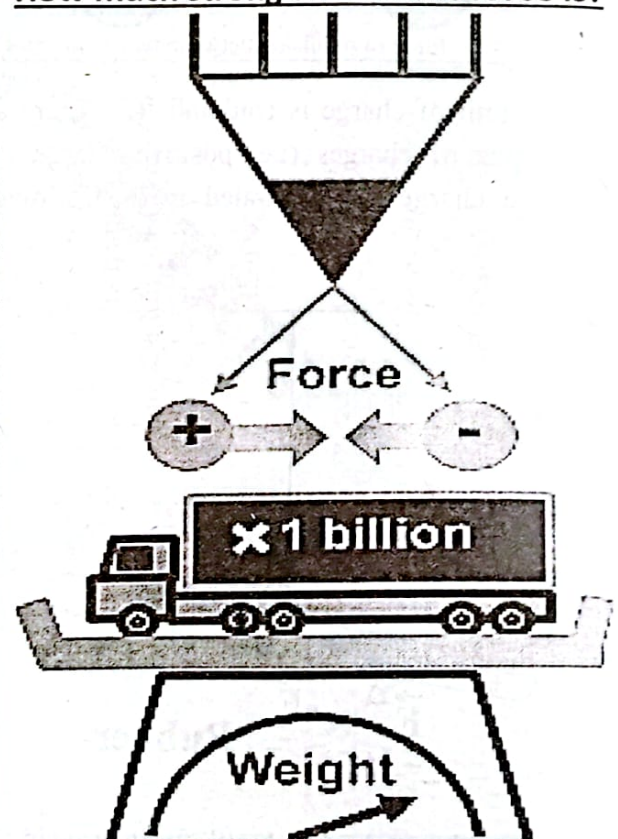
Secondly, the metal spheres are separated with the strip still in position, as shown in figure (b). The sphere 'A' is now positively charged (deficiency of electrons) and the sphere 'B' is negatively charged (excess of electrons).

Lastly, the metal strip is removed, and the charges remain on the spheres, as shown in figure (c).

In this way the electrostatic induction is used to charge objects.

Information

How much strong the electric force is?



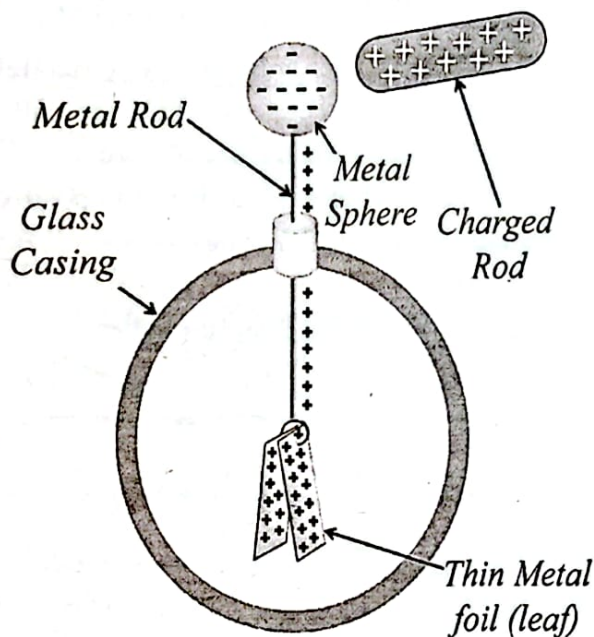
If we could separate the positive and negative charge in a pencil tip, the force pulling the charge back together exceeds the weight of a billion trucks.

Electroscope

Electroscope is a device used for detecting and testing the nature of charge on a body.

Construction:

A typical electroscope consists of metal rod having a metallic sphere at its upper end and two flexible metal leaves at the lower end enclosed in an insulated casing.



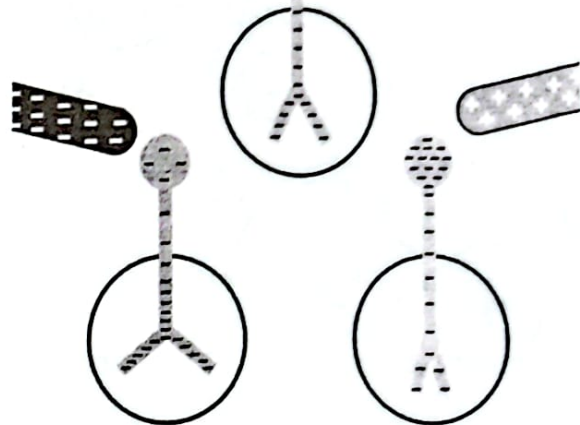
Detection of charge by an Electroscope:

When a charged body (say positive charged body) is brought near to the metallic sphere of an electroscope then due to electrostatic induction opposite charges (electrons) are accumulated at the sphere while same charges (positive charges) are repelled to the lower end (leaves). The leaves repel each other because of having same charges (positive charges) on them.

Testing the nature of charge by an Electroscope:

For testing the nature of charge on a body, the electroscope is charged first with some known charge (say negatively charged).

Previously Charged
Electroscope



- By bringing the same charged body (negatively charged body), the previously existed same charges are repelled to the leaves. As a result, the divergence of the leaves increases.
- By bringing the oppositely charged body (positively charged body), the previously existed opposite charges are attracted from the leaves. As a result, the divergence of the leaves decreases.

Coulomb's Law

Statement: The electrostatic force between two charges is directly proportional to the product of their magnitudes and inversely proportional to the square of the distance between them.

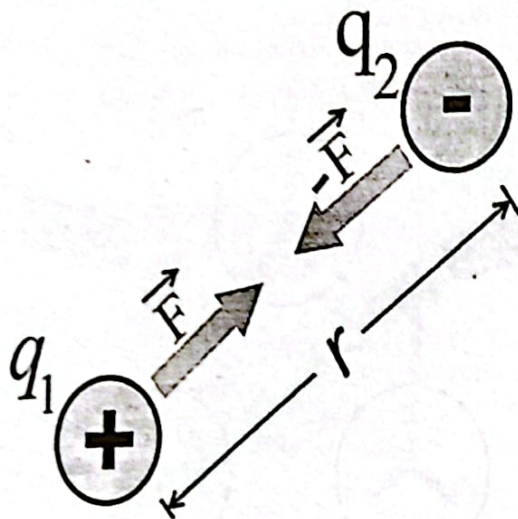
$$\text{i.e. } F_E \propto q_1 q_2$$

$$\text{and } F_E \propto \frac{1}{r^2}$$

$$\Rightarrow F_E \propto \frac{q_1 q_2}{r^2}$$

$$\Rightarrow F_E = k \frac{q_1 q_2}{r^2} \dots \dots \dots (1)$$

Where, k is the constant of proportionality, q_1 and q_2 are the charges, and r is the distance between them, as shown in the figure.



The constant k is known as coulombs constant equals to $9 \times 10^9 \text{ Nm}^2/\text{C}^2$ in vacuum that is given by

$$k = \frac{1}{4\pi \epsilon_0} \dots \dots \dots (2)$$

Where ϵ_0 is known as permittivity of free space.

Putting equation (2) in equation (1), we get

$$F_E = \frac{1}{4\pi \epsilon_0} \frac{q_1 q_2}{r^2} \dots \dots \dots (3)$$

Equation (3) is the mathematical form of coulomb's law in vacuum.

In a material medium other than vacuum, the coulomb's law takes the form

$$F_E = \frac{1}{4\pi \epsilon} \frac{q_1 q_2}{r^2} \dots \dots \dots (4)$$

Equation (4) is the mathematical form coulomb's law in a material medium, where ϵ is permittivity of the material medium.



Electric Field and its Intensity

The region around a charge in which a test charge would experience an electric force is called electric field.

The strength of the field at any point is called *electric field intensity* defined as, the electric force exerted on a unit positive charge at that point.

$$E = \frac{F}{+q} \dots \dots \dots (1)$$

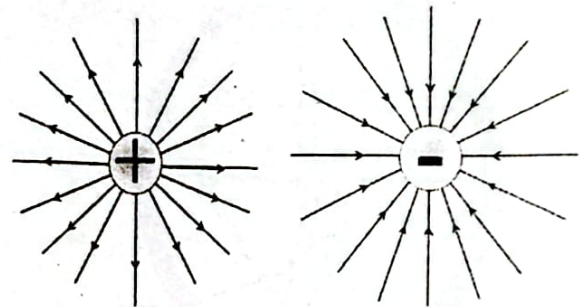
The electric field intensity is a vector quantity and its SI unit is N/C . In vector form, equation (1) can be written as

$$\vec{E} = \frac{\vec{F}}{+q} \dots \dots \dots (2)$$

Electric Field Lines:

The lines drawn in the direction of electric field intensity to visualize the electric field are called electric field lines (or electric lines of force).

The visualization of electric fields due to positive and negative charges is shown below.



Electric Potential

The electric potential energy 'U' per unit charge 'q' in an electric field is called electric potential 'V'.

Mathematically,

$$V = \frac{U}{q} \dots \dots \dots (1)$$

The electric potential energy 'U' is defined as, the amount of work done 'W' to move a charge 'q' from one point in the electric to another point.

i.e. $U = W$

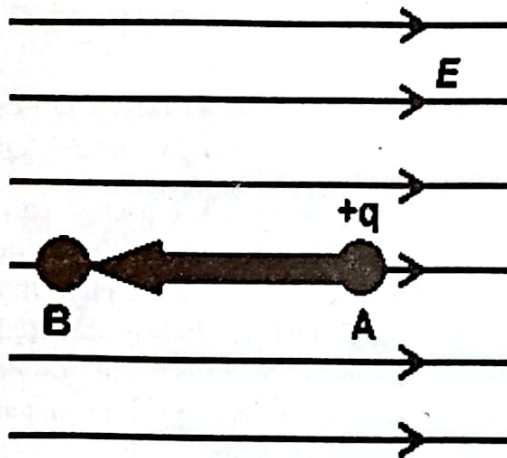
so, $(1) \Rightarrow V = \frac{W}{q} \dots \dots \dots (2)$

The electric potential is a scalar quantity, and its SI unit is *joule per coulomb* (JC^{-1}) which is equal to volt 'V'.

i.e.
$$1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}}$$

The potential at a point is 1 V, if 1 J of work is required to move a positive charge of 1 C from a point of zero potential to that point.

Consider a positive charge '+q' placed at point (A) in an electric field 'E' as shown in the figure.



The amount of work done by moving the charge '+q' from point (A) to point (B) is equal to the difference in potential energies the charge possesses at these points.

i.e.
$$W_{A \rightarrow B} = U_B - U_A$$

$$\Rightarrow \frac{W_{A \rightarrow B}}{q} = \frac{U_B}{q} - \frac{U_A}{q} \dots \dots \dots (3)$$

Here, $\frac{U_A}{q} = V_A$ and $\frac{U_B}{q} = V_B$

$$(3) \Rightarrow \frac{W_{A \rightarrow B}}{q} = V_B - V_A$$

or
$$V_B - V_A = \frac{W_{A \rightarrow B}}{q} \dots \dots \dots (4)$$

If point (B) is inside the electric field and point (A) is taken at infinity, then $V_A = 0$ and $V_B = V$. Now the equation (4) takes the simple form

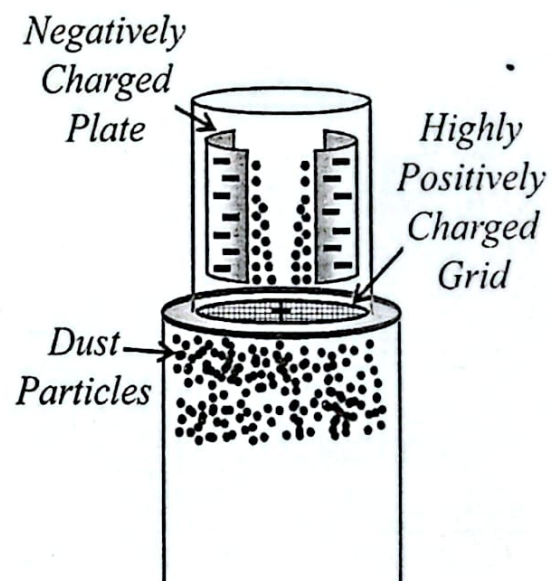
$$V = \frac{W}{q}$$

Practical Applications of Electrostatics

Electrostatic Precipitator and dust extraction:

The extraction of dust from the smoke in chimneys before releasing to the environment is called electrostatic precipitation.

For this purpose a highly positively charged grid and negatively charged plates are fixed inside the chimney, as shown in the figure.



When the rising smoke passes through the highly positively charged grid, the dust particles acquire positive charge, are attracted by the negatively charged plates and deposited on them. As a result the smoke coming out of the chimney is free from dust and other particles.

Electro painting:

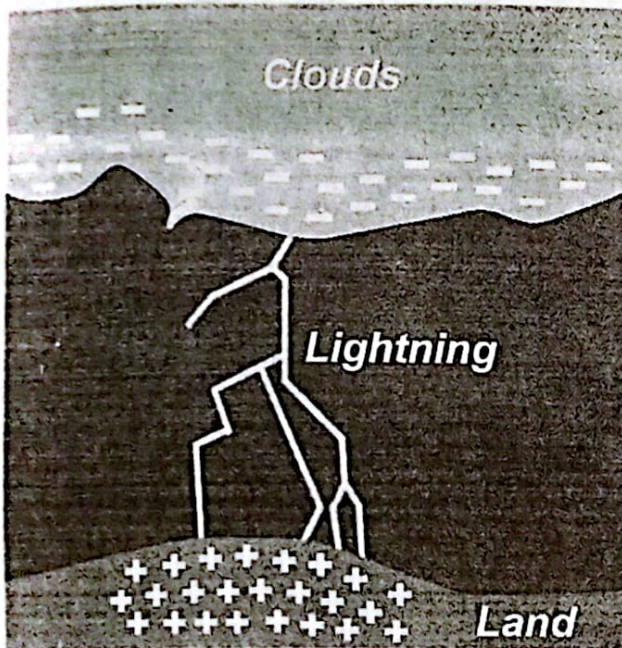
In electrostatic spray painting the electrostatically charged paint is sprayed through a gun. When sprayed from the gun, all the particles have same charge due to which they repel each other and distribute evenly through the surface and results in uniform coating. The other advantage is the decrease in the usage of paint. Due to electrostatic induction the charge particles of the paint induce opposite charge on the object being painted. As a

result the paint particles are attracted by the opposite charge on the object.

Dangers of Static Charge

Lightning:

As the particles in the cloud collide with each other, charges are transferred between them. Positive charge is buildup on smaller particles and negative charge on bigger particles. Due to gravity and wind, the bigger negatively charged particles are pushed to the bottom while the smaller positively charged particles rise to the top.



The negative charges on the bottom of the cloud induce positive charges on the ground. When the electric field between the cloud and the ground becomes large enough, the dielectric breakdown of air occurs (i.e. the air becomes a good conductor). As a result, about 20% to 25% of all the accumulated negative charges flow from the cloud to the ground. The air along the path is heated ($\sim 20,000^\circ\text{C}$) so that it glow like a bright streak of light.

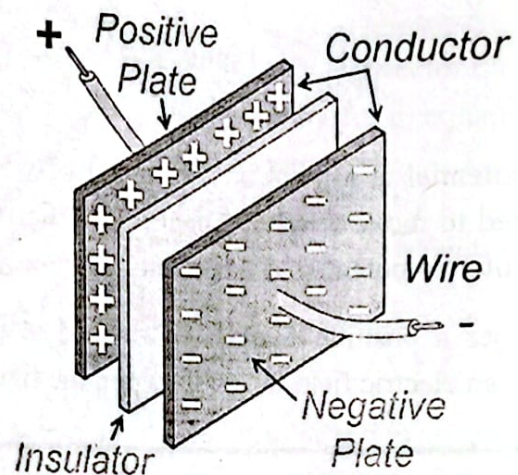


Capacitor

A capacitor is a device that stores electrical energy in an electric field.

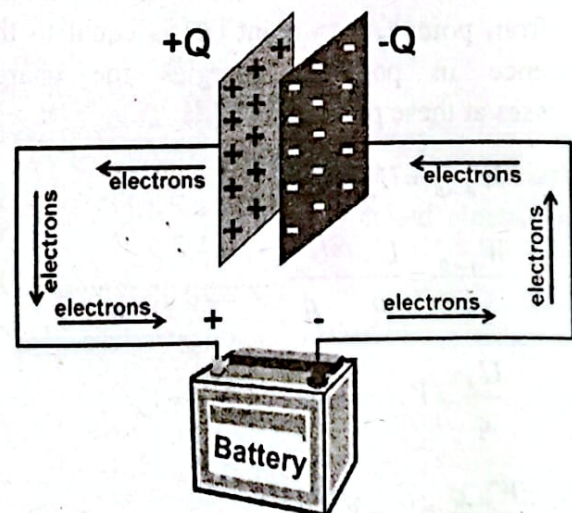
A capacitor consists of two conductors (known as the plates of the capacitor) separated from each other

usually by placing an insulator (dielectric) between them.

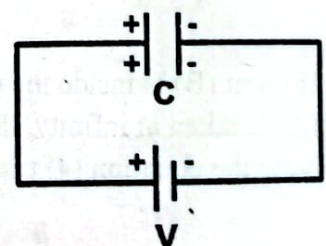


Both the plates of the capacitor carry charges of equal magnitude and opposite sign ($+Q$ and $-Q$).

Charging of a Capacitor: A capacitor can be charged by connecting the plates to the terminals of a battery. The electrons from the plate that is connected to the positive terminal of the battery are attracted by the positive terminal of the battery and pushed to the other plate that is connected to negative terminal as shown in the figure.



The plate from which the electrons are attracted acquires positive charge (deficiency of electrons) while the plate to which



the electrons are pushed acquires same amount of negative charge (excess of electrons).

An electric field is developed between the oppositely charged plates due to which the charges remain on the plates even the battery is removed.

Capacitance of a Capacitor

As the charge 'Q' increases on the plates, the potential difference 'V' across the plates also increases, i.e.

$$Q \propto V$$

or $Q = CV \dots \dots \dots (1)$

Here 'C' is the constant of proportionality, known as the capacitance of the capacitor.

$$(1) \Rightarrow C = \frac{Q}{V} \dots \dots \dots (2)$$

From equation (3), capacitance can be defined as; *the ratio of the magnitude of charge 'Q' on either plate to the magnitude of potential difference 'V' between them.*

The SI unit of capacitance is farad 'F', which can be defined from equation (1) as

$$(1) \Rightarrow 1F = \frac{1C}{1V}$$

The capacitance of a capacitor is 1F if 1C of charge on either plate induces a potential difference of 1V between the plates.

Since farad is a very large unit, so convenient units of capacitance are commonly used.

$$1\mu F = 10^{-6} F$$

$$\text{and } 1pF = 10^{-12} F$$

Types of Capacitors

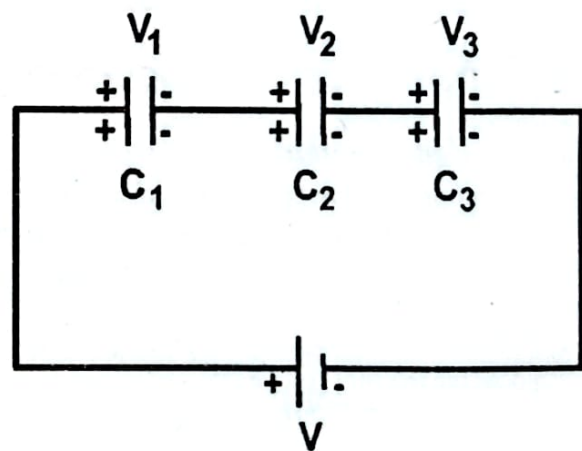
The capacitors are classified on the basis of their construction and the dielectric used. Each type has its own characteristics and applications. These capacitors may have fixed or variable capacitances.

The electrolytic tubular capacitor is the most popular because of having the highest capacitance. They consists of two thin aluminum foils with an electrolyte-soaked paper sheet placed between them and wound around one another.

Combinations of Capacitors

Series Combination:

In series combination, the capacitors are connected to the voltage source through one another (plate to plate) as shown in the figure.



Due to electrostatic induction, each plate of the capacitors acquires same amount of charge.

$$\text{i.e. } Q_1 = Q_2 = Q_3 = Q \dots \dots \dots (1)$$

But, the applied voltage 'V' of the source is divided on the capacitors,

i.e.

$$V = V_1 + V_2 + V_3 \dots \dots \dots (2)$$

As we know that

$$Q = CV$$

$$\Rightarrow V = \frac{Q}{C}$$

Now, equation (2) becomes

$$\frac{Q}{C_{eq}} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$$

$$\Rightarrow \frac{Q}{C_{eq}} = Q \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \right)$$

$$\Rightarrow \frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \dots \dots \dots (3)$$

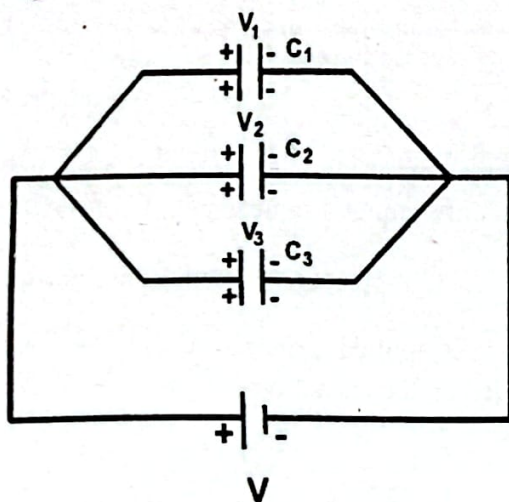
For more than three capacitors, equation (3) can be written as

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4} + \dots + \frac{1}{C_n} \dots \dots \dots (4)$$

Equation (4) shows that the equivalent capacitance of a series combination is smaller than the smallest individual capacitance.

Parallel Combination:

In parallel combination the capacitors are directly connected to the voltage source (different branches for individual capacitors), as shown in the figure.



Since each capacitor is directly connected to the voltage source, so the potential difference on each capacitor is equal to the applied voltage.

$$\text{i.e. } V_1 = V_2 = V_3 = V \dots \dots \dots (1)$$

But, the charge on each capacitor is different. The total charge 'Q' on the combination is equal to sum of the charges on all capacitors.

$$\text{i.e. } Q = Q_1 + Q_2 + Q_3 \dots \dots \dots (2)$$

As we know that

$$Q = CV$$

Now, equation (2) becomes

$$C_{eq}V = C_1V + C_2V + C_3V$$

$$\Rightarrow C_{eq}V = V(C_1 + C_2 + C_3)$$

$$\Rightarrow C_{eq} = C_1 + C_2 + C_3 \dots \dots \dots (3)$$

For more than three capacitors, equation (3) can be written as

$$C_{eq} = C_1 + C_2 + C_3 + C_4 + \dots + C_n \dots \dots \dots (4)$$

Equation (4) shows that the equivalent capacitance of a parallel combination is greater than the greatest individual capacitance.



EXERCISE

Multiple Choice Questions

1	When combing our hair, we shift electrons from our hair onto the comb. The charge on our hairs is			
	☐ Positive	B	☐ Negative	
	C ☐ zero	D	☐ infinite	
2	The unit of charge is			
	A ☐ farad	☐	☐ coulomb	
	C ☐ volt	D	☐ electron volt	
3	Initially, sphere A has a charge of $-50e$ and sphere B has a charge of $+20e$. The spheres are made of conducting material and are identical in size. If the spheres then touch, what is the resulting charge on sphere A?			
	A ☐ $+15e$	☐	☐ $-15e$	
	C ☐ $+35e$	D	☐ $-35e$	
4	If the distance between two charged particles is halved, the coulomb force between the two charged particles becomes			
	A ☐ Half	B	☐ One quarter	
	C ☐ Double	☐	☐ Four times	
5	The value of coulomb constant k , depends on			
	A ☐ Value of charges	☐	☐ Material medium	
	C ☐ Separation of charges	D	☐ All of those	
6	An additional capacitor is added to a group of capacitors already connected in series, the equivalent capacitance			
	A ☐ Increase	B	☐ Stay the same	
	☐ Decrease	D	☐ Goes to zero	
7	The unit of electric potential is			
	A ☐ farad	B	☐ coulomb	
	☐ volt	D	☐ NC^{-1}	
8	Four identical $1\mu F$ capacitors are connected together electrically. What is the least possible capacitance of the combination?			
	A ☐ $4\mu F$	B	☐ $1\mu F$	
	☐ $1/4\mu F$	D	☐ $1/8\mu F$	
9	A capacitor C has a charge Q . The actual charges on its plates are			
	A ☐ Q, Q	B	☐ $Q, 0$	
	☐ $Q, -Q$	D	☐ $Q/2, -Q/2$	

Conceptual Questions

1. Normally, objects with large number of electrons are electrically neutral, Why?

Ans. As we know that every material object is made up of atoms and every atom has equal number of protons (positive charge) and electrons (negative charge). As a result, the atom has no net charge. That is why objects are electrically neutral.

2. How does shuffling feet across a carpet cause hair to stand on our body?

Ans. When we shuffle feet on a carpet, transfer of charge occurs between the carpet and our body due to friction. Some of the electrons from the carpet transfer to our body and accumulate on our body's hair. Because of having same charge, the hair repel each other. As a result, the hair stands up on our body.

3. Why neutral objects are always attracted by charged objects? Not repelled.

Ans. When a charged body is brought near to a neutral body, then due to electrostatic induction, opposite charge in the neutral body is attracted towards the charged body. As we know that same charges attract each other, therefore the charged body will attract the neutral body towards itself.

4. Why the pieces of paper initially attracted by charged comb fly away when they touch it?

Ans. When the charged comb is brought near the pieces of paper, separation of charges occurs on the pieces due to electrostatic induction. As a result, the pieces are attracted to the charged comb due to the opposite charges on the comb and the surfaces of the pieces towards the comb.

However, when the pieces touch the comb, some of the charges on comb is transferred to the pieces. As like charges repel each other, the pieces are then repelled by comb and fly away.

5. Is it necessary for a charged body actually to touch the ball of electroscope for the leaves to diverge? Defend your answer.

Ans. No, it is not necessary for a charged body to touch the ball of electroscope for the leaves to diverge. As the charge body is brought near to the ball of the electroscope, like charges are repelled towards the leaves of the electroscope due to electrostatic induction and unlike charges are attracted to the ball of the electroscope. Now like charges are accumulated on the leaves. As like charges repel each other, the leaves diverge due to electrostatic repulsion.

6. How electrostatic painting is better than conventional spray painting?

Ans. When the particles of paint leave the spray gun, they gain negative charge. These negatively charged particles of paint repel each other, resulting uniform distribution of paint over the surface. Furthermore, these negative charges induce positive charge on the surface due to electrostatic induction. As a result, the particles of paint are attracted to the surface and reduces the usage of paint.

7. Why are lightning rods normally at a higher elevation than the buildings they protect?

Ans. The lightning rods are used for the protection of buildings during lightning storm. They provide easy path for the flow of huge amount of charge from the clouds to the ground during lightning storm. These rods are installed at higher elevation than the building for the reason that the lightning first hits the rods and not the building.

8. What would happen if two insulating plates were used instead of conducting plates to construct a capacitor?

Ans. Capacitors are charged by connecting its plates to the terminals of a battery. The battery draws free electrons from one plate and transfer them to the other plate. As a result, one plate acquires positive charge while the other acquires negative charge.

Since metals have large number of free electrons, in case of metallic plates, large number of electrons will be transferred from one plate to the other plate by the battery. Thus, there will be large amount of charge deposited on either plate.

On the other hand, insulators have few or no free electrons, so in case of insulating plates, the deposition of charge on the plates will be very small.

9. The sum of the charges on both plates of a capacitor is zero. What does a capacitor store?

Ans. Capacitors do not store charge. They actually store the separation of opposite charges, i.e. if one plate has 1 C of positive charge stored on it, the other plate will have 1 C of negative charge. Thus, the total (net) charge on capacitor is zero.

Capacitors store electrical energy in an electric field between the oppositely charge plates.

10. If you wish to store a large amount of energy in a capacitor bank, would you connect capacitors in series or parallel? Explain.

Ans. As we know that the total energy of a combination is given by

$$E = \frac{1}{2} C_{eq} V^2 \dots \dots \dots (1)$$

Equation (1) shows that the energy stored in a combination is proportional to the equivalent capacitance of the combination and square of the voltage applied to the combination.

According to the above equation, both ways are possible. That is, in parallel combination, the capacitances add up, thus the energy stored increases. While, in series combination, the equivalent capacitance reduces, so we will need much higher voltage to achieve this.

However, for a given fixed voltage, parallel combination of capacitors will store more energy than the series combination.



Numerical Questions

1. Determine the magnitude of the electric force on the electron of a hydrogen atom exerted by single proton that is the atom's nucleus. Assume the average distance between the electron and proton is $r = 5.3 \times 10^{-11} \text{ m}$ and the charge on electron and proton is $1.6 \times 10^{-19} \text{ C}$.

Given data :

Distance between Proton & Electron $r = 5.3 \times 10^{-11} \text{ m}$

Charge on Proton & Electron $q = 1.6 \times 10^{-19} \text{ C}$

Value of Coulomb Constant $k = 9 \times 10^9 \text{ Nm}^2/\text{C}^2$

Required :

Electric Force between Proton & Electron $F_e = ?$

Solution :

As we know that

$$F_e = k \frac{q_1 q_2}{r^2}$$

$$\Rightarrow F_e = k \frac{q^2}{r^2} \quad (\text{Put the values})$$

$$F_e = \frac{9 \times 10^9 \times (1.6 \times 10^{-19})^2}{(5.3 \times 10^{-11})^2}$$

$$F_e = \frac{9 \times 10^9 \times 2.56 \times 10^{-38}}{2.81 \times 10^{-21}}$$

$$F_e = \frac{2.3 \times 10^{-28}}{2.81 \times 10^{-21}}$$

$$F_e = 8.2 \times 10^{-8} \text{ N}$$

2. A $5 \mu\text{C}$ point charge is placed 20 cm from $10 \mu\text{C}$ point charge. (a) Calculate the force experienced by the $5 \mu\text{C}$ charge. (b) What is the force on the $10 \mu\text{C}$ charge? (c) What is the field strength 20 cm from $10 \mu\text{C}$ point charge?

Given data :

Charge $q_1 = 5 \mu\text{C} = 5 \times 10^{-6} \text{ C}$

Charge $q_2 = 10 \mu\text{C} = 10 \times 10^{-6} \text{ C}$

Distance $r = 20 \text{ cm} = 20 \times 10^{-2} \text{ m}$

Coulomb constant $k = 9 \times 10^9 \text{ Nm}^2/\text{C}^2$

Required :

- a) Force experienced by $q_1 (5 \mu\text{C})$ charge

$$F_1 = ?$$

- b) Force experienced by $q_2 (10 \mu\text{C})$ charge

$$F_2 = ?$$

- c) Electric field intensity due to q_2 at 20 cm

$$E = ?$$

Solution :

a & b) As we know that

$$|F_1| = |F_2| = k \frac{q_1 q_2}{r^2} \quad (\text{Put the values})$$

$$|F_1| = |F_2| = \frac{9 \times 10^9 \times 5 \times 10^{-6} \times 10 \times 10^{-6}}{(20 \times 10^{-2})^2}$$

$$|F_1| = |F_2| = \frac{45 \times 10^{-3}}{40 \times 10^{-4}}$$

$$|F_1| = |F_2| = \frac{45 \times 10^{-3+4}}{40}$$

$$|F_1| = |F_2| = \frac{45 \times 10^1}{40}$$

$$|F_1| = |F_2| = 11.25 \text{ N}$$

b) We also know that

$$E = k \frac{q}{r^2} \dots \dots \dots (1)$$

Here, $q = q_2 = 10 \times 10^{-6} \text{ C}$

and $r = 20 \text{ cm} = 20 \times 10^{-2} \text{ m}$

(Put the values in equ. 1)

$$(1) \Rightarrow E = \frac{9 \times 10^9 \times 10 \times 10^{-6}}{(20 \times 10^{-2})^2}$$

$$E = \frac{90 \times 10^1}{400 \times 10^{-4}}$$

$$E = \frac{9 \times 10^{1+4}}{40}$$

$$E = 2.25 \times 10^4 \text{ N/C}$$

3. In a certain region of space, a uniform electric field has a magnitude of $4.6 \times 10^4 \text{ N/C}$ and

points in the positive x -direction. Find the magnitude and direction of the force this field exerts on a charge of (a) $+2.80\mu\text{C}$ and (b) $9.30\mu\text{C}$.

Given data :

Electric field intensity ' E ' = $4.60 \times 10^4 \text{ N/C}$

Direction of E = positive x -direction

Charge ' q_1 ' = $+2.80\mu\text{C} = 2.80 \times 10^{-6} \text{ C}$

Charge ' q_2 ' = $-9.30\mu\text{C} = 9.30 \times 10^{-6} \text{ C}$

Required :

a) Force on charge q_1 ' F_1 ' = ?

b) Force on charge q_2 ' F_2 ' = ?

Solution :

a) As we know that

$$E = \frac{F}{q}$$

$$\Rightarrow E = \frac{F_1}{q_1}$$

$$\Rightarrow F_1 = q_1 E \quad (\text{Put the values})$$

$$F_1 = 2.80 \times 10^{-6} \times 4.60 \times 10^4$$

$$F_1 = 12.88 \times 10^{-6+4}$$

$$F_1 = 12.9 \times 10^{-2}$$

$$F_1 = 0.129 \text{ N}$$

Since F_1 is positive, so its direction is the same as that of the electric field intensity E (i.e. **+ive x -direction**).

b) Similarly

$$F_2 = q_2 E \quad (\text{Put the values})$$

$$F_2 = -9.30 \times 10^{-6} \times 4.60 \times 10^4$$

$$F_2 = -42.78 \times 10^{-6+4}$$

$$F_2 = -42.8 \times 10^{-2}$$

$$F_2 = -0.428 \text{ N}$$

Since F_2 is negative, so its direction is opposite to that of the electric field intensity E (i.e. **-ive x -direction**).

4. The potential difference between two points is 110 V. When an unknown charge is moved between those two points, the work done is the amount of charge?

Given data :

Potential difference ' V ' = 110V

Work done ' W ' = 550 J

Required :

Charge ' q ' = ?

Solution :

As we know that

$$V = \frac{W}{q}$$

$$\Rightarrow q = \frac{W}{V} \quad (\text{Put the values})$$

$$q = \frac{550}{110}$$

$$q = 5 \text{ C}$$

5. The capacitance of a capacitor is 3200 pF. If the potential difference between the plates is 220 V. What is the charge on each of its plates?

Given data :

Capacitance ' C ' = $3200 \text{ pF} = 3200 \times 10^{-12} \text{ F}$
 $= 3.2 \times 10^{-9} \text{ F} = 3.2 \times 10^{-9} \text{ F}$

Potential difference ' V ' = 220V

Required :

Charge on each plate ' Q ' = ?

Solution :

As we know that

$$Q = CV \quad (\text{Put the values})$$

$$Q = 3.2 \times 10^{-9} \times 220$$

$$Q = 3.2 \times 10^{-9} \times 220$$

$$Q = 704 \times 10^{-9} \text{ C}$$

$$Q = 0.704 \times 10^{-6} \text{ C}$$

$$Q = 0.704 \mu\text{C}$$

6. Three capacitors of capacitance $1\mu\text{F}$, $2\mu\text{F}$ and $3\mu\text{F}$ are connected in series to a 110 V battery. Calculate the equivalent capacitance and voltage across each capacitor.

Given data :Capacitance ' C_1 ' = $1\mu F = 1 \times 10^{-6} F$ Capacitance ' C_2 ' = $2\mu F = 2 \times 10^{-6} F$ Capacitance ' C_3 ' = $3\mu F = 3 \times 10^{-6} F$ Volatage ' V ' = $110V$ **Required :**a) Equivalent Capacitance ' C_{eq} ' = ?

b) Voltage across each capacitor:

$$V_1 = ? \quad V_2 = ? \quad V_3 = ?$$

Solution :

a) As we know that the equivalent capacitance of series combination is given by

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \quad (\text{Put the values})$$

$$\frac{1}{C_{eq}} = \frac{1}{1} + \frac{1}{2} + \frac{1}{3} = \frac{6+3+2}{6} = \frac{11}{6}$$

$$\Rightarrow C_{eq} = \frac{6}{11}$$

$$C_{eq} = 0.54\mu F$$

b) We also know that

$$Q = CV$$

$$\Rightarrow V = \frac{Q}{C}$$

$$\Rightarrow V_1 = \frac{Q_1}{C_1}, \quad V_2 = \frac{Q_2}{C_2} \quad \text{and} \quad V_3 = \frac{Q_3}{C_3} \dots \dots \dots (1)$$

Since the charge on each capacitor is the same in series combination,

i.e. $Q_1 = Q_2 = Q_3 = Q = C_{eq}V$ (put the values)

$$Q = 0.54 \times 10^{-6} \times 110$$

$$Q = 59.4 \times 10^{-6} C$$

Put the values in equation (1)

$$(1) \Rightarrow \begin{cases} V_1 = \frac{59.4 \times 10^{-6}}{1 \times 10^{-6}} = 59.4 V \\ V_2 = \frac{59.4 \times 10^{-6}}{2 \times 10^{-6}} = 29.7 V \\ V_3 = \frac{59.4 \times 10^{-6}}{3 \times 10^{-6}} = 19.8 V \end{cases}$$

7. Two capacitors of capacitance $2pF$ and $3pF$ re connected in parallel to a $9V$ battery. Calculate the equivalent capacitance and the charge on each capacitor.

Given data :Capacitance ' C_1 ' = $2 pF = 2 \times 10^{-12} F$ Capacitance ' C_2 ' = $3 pF = 3 \times 10^{-12} F$ Voltage ' V ' = $9V$ **Required :**a) Equivalent capacitance ' C_{eq} ' = ?

b) Charge on each capacitor:

$$Q_1 = ? \quad Q_2 = ? \quad Q_3 = ?$$

Solution :

a) As we know that the equivalent capacitance of parallel combination is give by

$$C_{eq} = C_1 + C_2 \quad (\text{Put the values})$$

$$C_{eq} = 2 + 3$$

$$C_{eq} = 5 pF$$

b) We also know that

$$Q = CV$$

$$\Rightarrow Q_1 = C_1 V_1 \quad \text{and} \quad Q_2 = C_2 V_2 \dots \dots \dots (1)$$

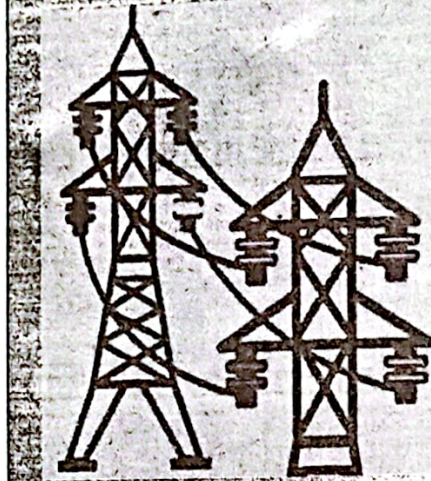
Since the potential difference across each capacitor is the same in parallel combination.

$$\text{i.e. } V_1 = V_2 = V_3 = V = 9V$$

Put the values in equation (1)

$$(1) \Rightarrow \begin{cases} Q_1 = 2 \times 10^{-12} \times 9 = 18 \times 10^{-12} C = 18 pC \\ Q_2 = 3 \times 10^{-12} \times 9 = 27 \times 10^{-12} C = 27 pC \end{cases}$$





UNIT 14

CURRENT ELECTRICITY

Electric Current

The rate of flow of charge through an area is called electric current.

If ΔQ is the amount of charge flowing through any cross-sectional area in time ' Δt ', then the current ' I ' is given by

$$I = \frac{\Delta Q}{\Delta t}$$

The flowing charges that comprise the electric current are known as charge carriers. They may be:

- Negative charges (i.e. electrons) in metals.
- Positive charges (i.e. positive ions) in particle accelerators.
- Both positive and negative ions in gases and electrolytes.

The SI unit of electric current is ampere 'A' which is defined as

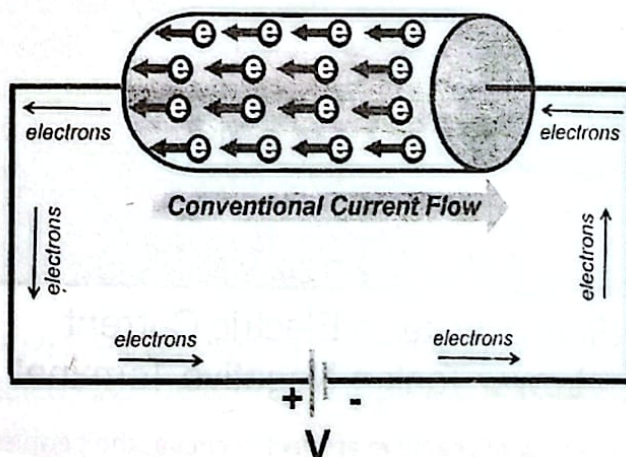
$$1A = \frac{1C}{1s}$$

The electric current is 1A, if 1C of charge flows through a region / point in 1s.

Conventional Current

Conventional current is the current whose direction is opposite to the flow of negative charges (electrons).

Consider a metal rod is connected to the terminals of the battery as shown in the figure.



As shown in the figure, the current in the metal is due to negative charges (electrons) which flow from the negative terminal of the battery to the positive terminal. But, before the discovery of electrons, it was assumed that the current in metals is due to positive charges which flow from positive terminal to negative terminal. This assumed direction of current flow is now called conventional current.

Since the positive charge moving in one direction is equivalent to negative charge moving in the opposite direction, so this convention is still used.

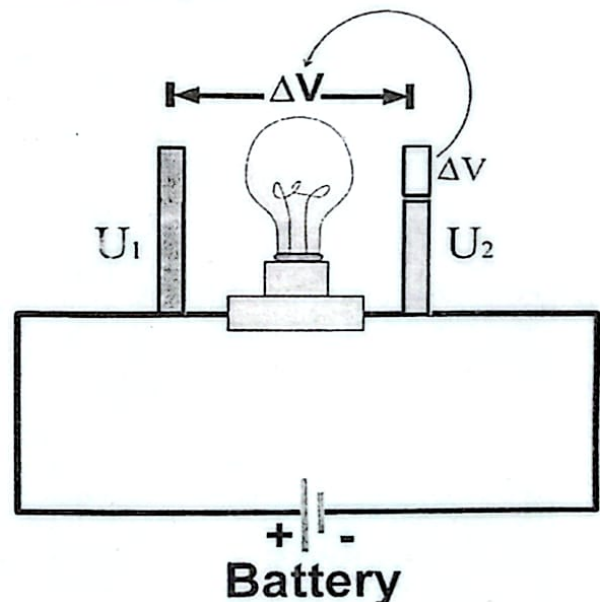


Potential Difference and EMF

Potential Difference:

The difference in electric potential (potential energy per unit charge) between two points in an electric circuit is called potential difference.

Consider a bulb connected across a battery as shown in the figure.



The charge leaving the positive terminal of the battery has higher potential energy ' U_1 '. Some of the electric potential energy is converted into light (non-electrical energy) in the bulb. So, the charge passed through the bulb has lower electric potential energy ' U_2 '

i.e. $U_1 > U_2$

As a result, there is a difference in potential energy per unit charge (electric potential) between the sides of the bulb, which is known as potential difference, given by

$$\Delta V = \frac{\Delta U}{q}$$

Electromotive Force (EMF)

The energy spent per unit positive charge by the source to move it from the point of lower potential (negative terminal) to the point of higher potential (positive terminal) within the source is termed as emf, denoted by ' ϵ '.

Mathematically;
$$\epsilon = \frac{W}{q}$$

The unit of emf is the same as that of electric potential i.e. volt 'V'.

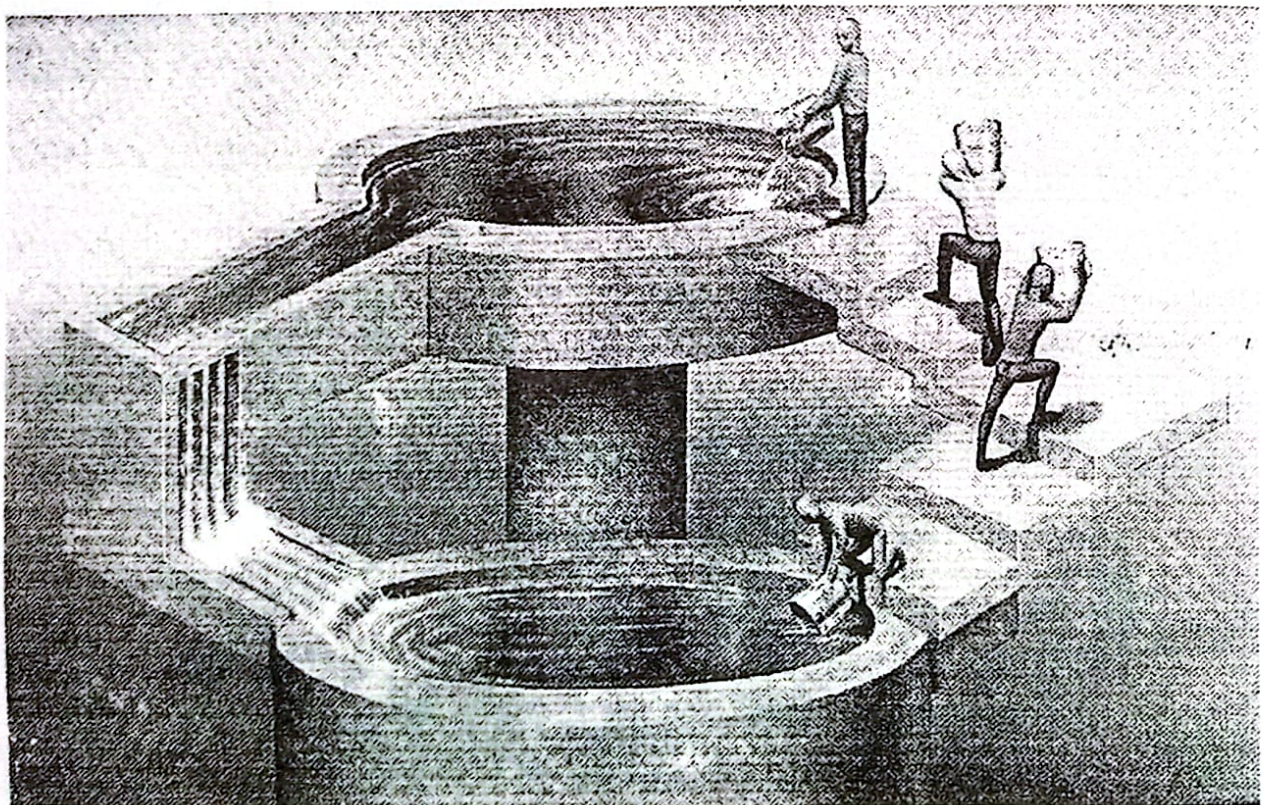
When a battery is connected across an appliance such as electric bulb, the positive charges leaving the positive terminal lose some of the electric potential energy in the bulb and enter into the negative terminal of the battery. Therefore, a work is to be done inside the battery to bring them from lower potential to higher potential. This work done per unit positive charge within the battery is known as emf.

A device which converts non-electrical energy into electrical energy is called *emf source*. e.g. battery, generator, solar panel, etc.



CONCEPT

(Optional)



People = emf
Upper Tank = Positive Terminal

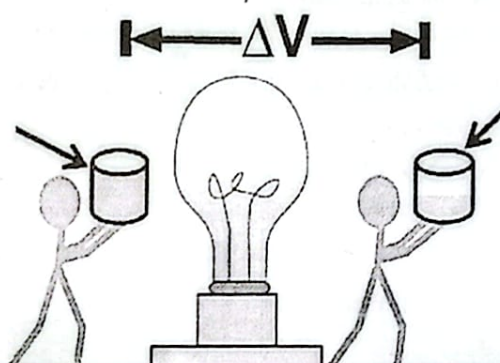
Flow of water = Electric Current
Lower Tank = Negative Terminal

Like the emf source such as battery which sustains the flow of charge in an electric circuit, the people must do work to sustain the flow of water.



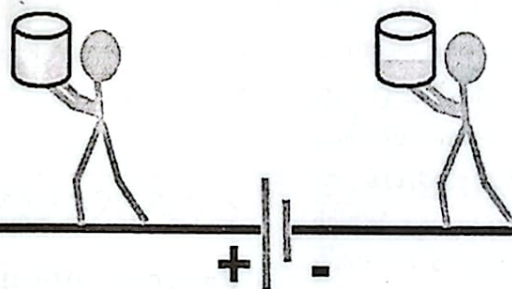
C O N C E P T

Higher Energy
per unit charge
(Higher Electric
Potential)



Lower Energy
per unit charge
(Lower Electric
Potential)

The difference in Electric Potential
appears as **Potential difference**
across the appliance



Battery

Ohm's Law

Statement: The current through a conductor is directly proportional to the voltage applied across it as long as the temperature and its physical state is kept constant.

i.e.

$$I \propto V$$

$$\Rightarrow I = \left(\frac{1}{R}\right)V \dots \dots \dots (1)$$

Where, $1/R$ is a constant of proportionality and R (known as *resistance*) is the opposition to the flow of current.

Resistance is the intrinsic property of the conductor, whose value is independent of the value of V and I , and depends upon:

- The nature of the material of the conductor.
- Dimensions (length and area of cross-section)
- Temperature

Equation (1) can be written as

$$V = IR \dots \dots \dots (2)$$

Equation (2) is the mathematical form of Ohm's law.

Limitations of Ohm's law:

Ohm's law is obeyed the best only by metallic conductors because their resistance does not change. Many electrical devices such as light bulb does not obey ohm's law because their resistance varies significantly due the variation in temperature.

Electrical Resistance

The opposition offered to the flow of charges (current) is called electrical resistance.

From Ohm's law

$$R = \frac{V}{I} \dots \dots \dots (1)$$

Mechanism of Electrical Resistance:

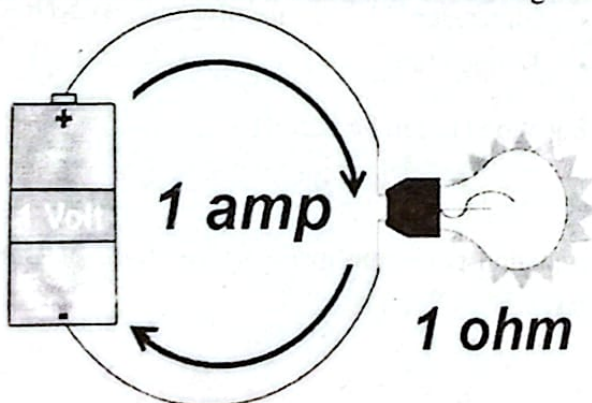
As we know that the current in conductors is due to the flow of free electrons. The free electrons during their motion through the conductor collide with the fixed atoms and lose some of their energy. As a result, the flow of free electrons (i.e. current) is opposed due to these collisions. Which is termed as resistance.

Unit of Resistance:

The SI unit of resistance is ohm (Ω) which is defined from equation (1) as

$$1\Omega = \frac{1V}{1A}$$

The resistance of a device is 1Ω , if a potential difference of 1V causes a current of 1A through it.



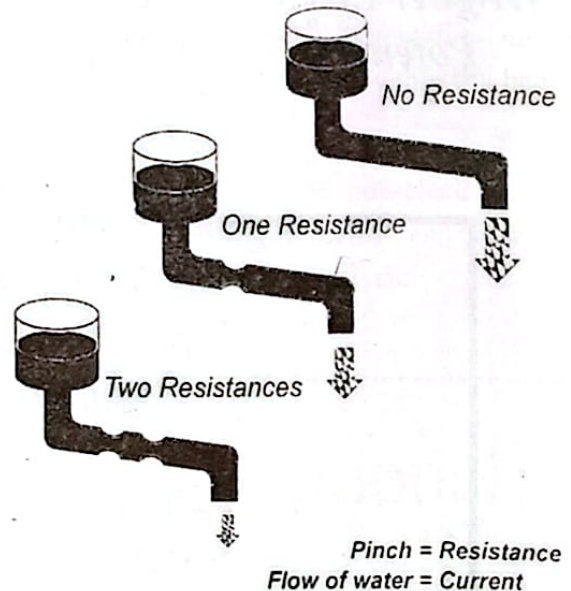
Since ohm is a very small unit, so other convenient units of resistance are

$$1k\Omega = 10^3\Omega$$

$$1M\Omega = 10^6\Omega$$

**CONCEPT**

(Optional)

**Factors upon which Resistance depends**

It is experimentally proved that the electrical resistance of a conductor depends upon the following factors if the temperature is kept constant.

- Length of the conductor:**

The resistance of a conductor is directly proportional to its length.

i.e.

$$R \propto L \dots \dots \dots (1)$$

- Area of cross-section of the conductor:**

The resistance of a conductor is inversely proportional to its area of cross-section.

i.e.

$$R \propto \frac{1}{A} \dots \dots \dots (2)$$

■ Nature of the material of the conductor:

Different conductors have different values of resistance. e.g. copper has lower resistance than aluminum.

Combining relations (1) and (2), we get

$$R \propto \frac{L}{A}$$

$$\Rightarrow R = \rho \frac{L}{A} \dots \dots \dots (3)$$

Where 'ρ' is the constant of proportionality, known as resistivity (or specific resistance). Each conductor has a specific value of resistivity which depends on its nature.

Dependence of resistance on temperature:

The resistance of a conductor also depends upon its temperature. As the temperature of a conductor increases, the vibrational kinetic energy of the atoms also increases. Due to the increase in the vibrations of the atoms, their collisions with the free electrons also increases. As a result, the resistance of the conductor increases.

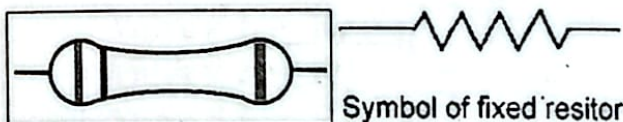
Resistors

A device (or circuit component) that has a specific value of resistance is called resistor.

Resistors may have fixed value of resistance (called fixed resistors) or may have variable value (called variable resistors).

Fixed Resistors:

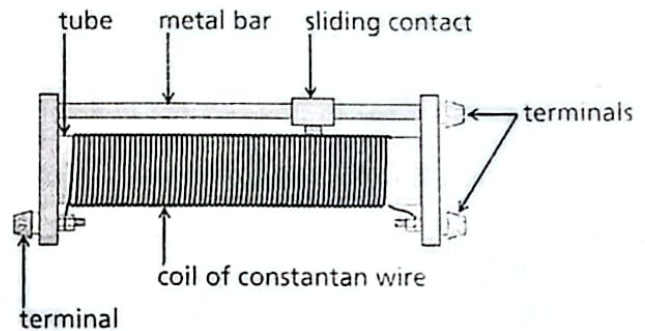
The resistors which have fixed value of resistance (i.e. their resistance cannot be changed) are called fixed resistors. They are made up of carbon.



Symbol of fixed resistor

Variable Resistors:

The resistors whose resistance can be changed are called variable resistors. They are made from resistive wires of special alloys such as constantan (an alloy of 60% Copper and 40% Nickel). The wire is wound on a tube with two fixed contacts and a sliding contact on a metal bar above the tube. They are useful in laboratory experiments.

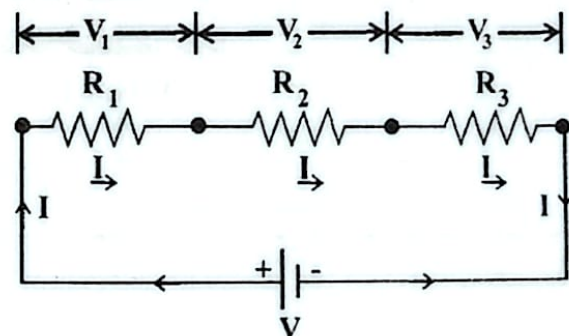


Symbol of variable resistor

Combinations of Resistors

Series Combination:

In series combination, the resistors are connected to the voltage source through one another (i.e. there is a single path for the flow of current) as shown in the figure.



In series combination, the same current passes through all resistors.

$$\text{i.e. } I_1 = I_2 = I_3 = I \dots \dots \dots (1)$$

But, the applied voltage 'V' is divided between the resistors.

i.e. $V = V_1 + V_2 + V_3 \dots \dots \dots (2)$

By Ohm's law,

$$V = IR_{eq}$$

So,

$$\begin{aligned} (2) \Rightarrow IR_{eq} &= IR_1 + IR_2 + IR_3 \\ \Rightarrow IR_{eq} &= I(R_1 + R_2 + R_3) \\ \Rightarrow R_{eq} &= R_1 + R_2 + R_3 \dots \dots \dots (3) \end{aligned}$$

For more than three resistors, equation (3) can

be written as

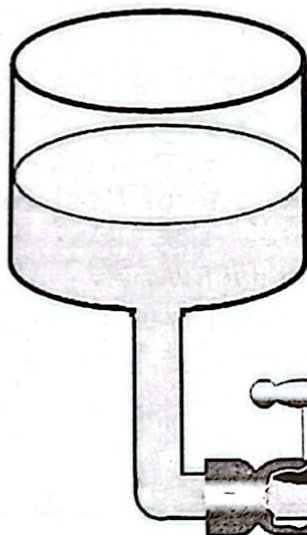
$$R_{eq} = R_1 + R_2 + R_3 + \dots + R_n \dots \dots \dots (4)$$

Equation (4) shows that the equivalent resistance of the series combination is greater than the greatest individual resistance.



CONCEPT

(Optional)



To show that the current through each resistor in series combination is the same

The setup is analogous to the series combination of resistors. Each valve represents a resistor and the flow of water represents the flow of current.

The amount of water flowing through all the three valves is the same which is equal to the amount of water flowing through the least opened valve #3.

Valve # 1
= R_1

<

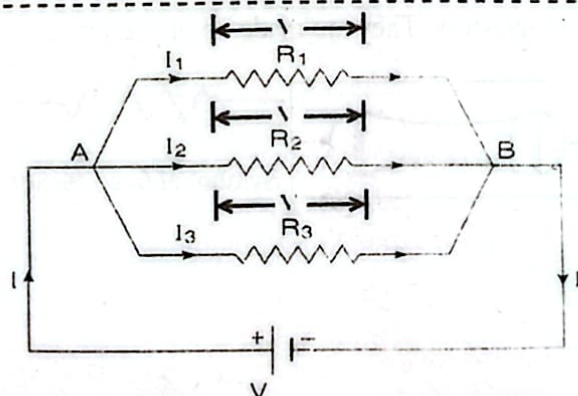
Valve # 2
= R_2

<

Valve # 3
= R_3

Parallel Combination:

In parallel combination, the resistors are connected directly to the voltage source (i.e. there are multiple paths for the flow of current) as shown in the figure.



In parallel combination, the potential difference across each resistor is the same because all the resistors are connected directly to the voltage source.

i.e. $V_1 = V_2 = V_3 = V \dots \dots \dots (1)$

But, the current through each resistance is different. The total current through the combination is given by

$$I = I_1 + I_2 + I_3 \dots \dots \dots (2)$$

By Ohm's law

$$V = IR_{eq}$$

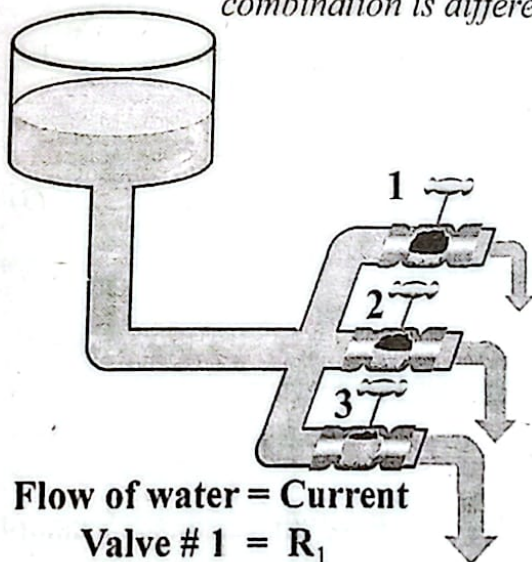
$$\Rightarrow I = \frac{V}{R_{eq}}$$

$$\text{So, (2)} \Rightarrow \frac{V}{R_{eq}} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$



CONCEPT (Optional)

To show that the current through each resistance in parallel combination is different



Flow of water = Current

Valve # 1 = R_1

Valve # 2 = R_2

Valve # 3 = R_3

The flow of water is different from each valve, depends on how much the valve is opened.

$$\Rightarrow \frac{V}{R_{eq}} = V \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right)$$

$$\Rightarrow \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \dots \dots \dots (3)$$

For more than three resistors, equation (3) can be written as

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n} \dots \dots \dots (4)$$

Equation (4) shows that the equivalent resistance of the parallel combination is smaller than the smallest individual resistance.

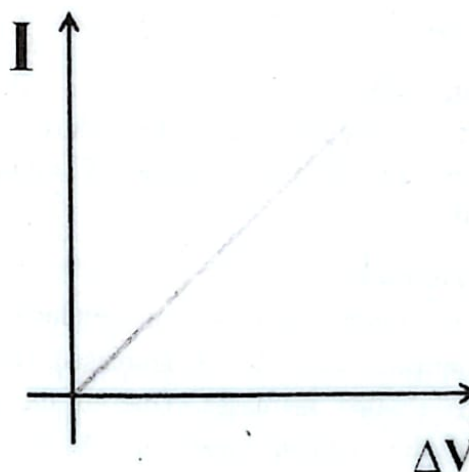


The I-V Characteristics for Ohmic and Non-ohmic Conductors

I-V Characteristics for Ohmic Conductors:

The conductors which obey Ohm's law are called ohmic conductors.

The I-V graph of ohmic conductors is a straight line with slope equals to $\frac{1}{R}$ as shown in the figure.



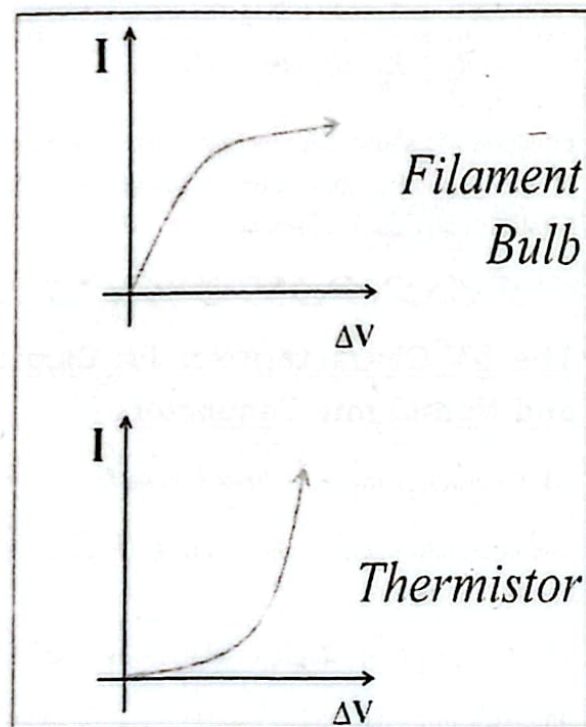
The figure shows that the slope $\frac{1}{R}$ is constant.

which means that Ohm's law obeys only for metallic conductors whose resistance remains constant for different values of voltage and current.

I-V Characteristics for Non-ohmic Conductors:

The conductors which do not obey Ohm's law are called non-ohmic conductors.

The I-V graph of non-ohmic conductors is not a straight line. The I-V graphs of filament bulb and thermistor are shown in the following figure.



The figure shows that the slope ' $\frac{1}{R}$ ' is not constant, which means that ohm's law is not obeyed by non-ohmic conductors whose resistance changes for different values of voltage and current.

Filament Bulb:

A filament bulb is a non-ohmic conductor. As the potential difference ' ΔV ' is increased, the current through it also increases. Due to the flow of current, the filament heats up. As a result of increase in the temperature, the resistance also increases.

As shown in the figure, at large values of potential difference, large change shows small increase in current through the filament.

Thermistor:

Thermistor is a short name for *thermal resistor* whose resistance depends significantly on

temperature. Usually, the resistance of a thermistor decreases with the increase in temperature.

For small values of potential difference, a very small (almost negligible) current passes through the thermistor. But, when the potential difference is increased the current through it also increases, due to which its temperature rises. As a result, the resistance decreases sharply and shows a very large increase in current for a very small increase in potential difference.

**Electrical Power & Joule's Law****Electrical Energy:**

The energy lost or gained by a charge ' Q ' going through a region having potential difference ' V ' is called electrical energy.

Mathematically;

$$E = QV \dots \dots \dots (1)$$

$$\left(\because V = \frac{W}{Q} = \frac{E}{Q} \right)$$

Where,

$$Q = It \dots \dots \dots (2)$$

$$\left(\because I = \frac{Q}{t} \right)$$

$$(1) \Rightarrow E = It \times V \dots \dots \dots (3)$$

By Ohm's law

$$V = IR$$

Now, equation (3) becomes

$$(3) \Rightarrow E = It \times IR$$

$$\Rightarrow E = I^2 Rt \dots \dots \dots (4)$$

As we know that

$$I = \frac{V}{R} \dots \dots \dots (5)$$

$$(\because V = IR)$$

Put equation (5) in equation (4)

$$\begin{aligned}(5) \Rightarrow E &= \left(\frac{V}{R}\right)^2 Rt \\ \Rightarrow E &= \frac{V^2}{R^2} \times Rt \\ \Rightarrow E &= \frac{V^2}{R} t \dots\dots\dots(6)\end{aligned}$$

Equations (3), (4) and (6) are used to calculate the electrical energy.

Joule's Law:

Statement: The amount of heat 'H' generated in a resistor is directly proportional to:

- Square of the current 'I' through it.
i.e. $H \propto I^2 \dots\dots\dots(1)$
- Its resistance
i.e. $H \propto R \dots\dots\dots(2)$
- Duration of time for which the current passes through it.
i.e. $H \propto t \dots\dots\dots(3)$

Combining equations (1), (2) and (3), we get

$$\begin{aligned}H &\propto I^2 Rt \\ \Rightarrow H &= \frac{I^2 Rt}{J} \dots\dots\dots(4)\end{aligned}$$

Where 'J' is the mechanical equivalent of heat. Its value depends upon the units of work and heat.

Electrical Power:

The rate at which the work is done in an electric circuit is called electrical power.

Mathematically;

$$P = \frac{W}{t} = \frac{E}{t} \dots\dots\dots(1)$$

Where 'E' is the electrical energy consumed in the circuit, given by

$$E = Q \times V \dots\dots\dots(2)$$

$$\text{But, } Q = It \quad \left(\because I = \frac{Q}{t} \right)$$

$$\text{So, } (2) \Rightarrow E = It \times V \dots\dots\dots(3)$$

Put equation (3) in equation (1), we get

$$\begin{aligned}(1) \Rightarrow P &= \frac{It \times V}{t} \\ \Rightarrow P &= IV \dots\dots\dots(4)\end{aligned}$$

By Ohm's law,

$$V = IR$$

So equation (4) can also be written as

$$\begin{aligned}(4) \Rightarrow P &= I(IR) \\ \Rightarrow P &= I^2 R \dots\dots\dots(5)\end{aligned}$$

As we know that

$$I = \frac{V}{R} \quad (\because V = IR)$$

$$\begin{aligned}(5) \Rightarrow P &= \left(\frac{V}{R}\right)^2 R \\ P &= \frac{V^2}{R^2} \times R \\ \Rightarrow P &= \frac{V^2}{R} \dots\dots\dots(6)\end{aligned}$$

Equations (4), (5) and (6) are used to calculate the electrical power.

Unit of Electrical Power: The SI unit of electrical power is watt 'W', which is defined from equation (4) as

$$1 \text{ W} = 1 \text{ A} \times 1 \text{ V}$$

A power of 1W is said to be consumed in an electric circuit if a potential difference of 1V cause a current of 1A to flow through it.

Kilowatt-hour (kWh):

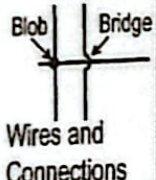
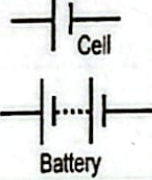
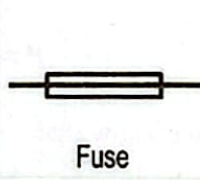
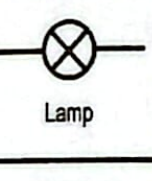
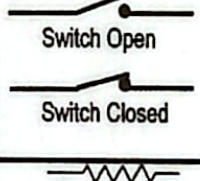
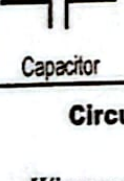
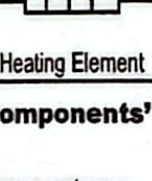
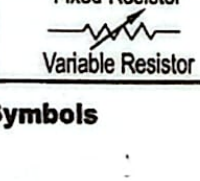
Kilowatt-hour is a unit of electrical energy for which the tariff (cost of energy) is decided by electricity supply company. It is the amount of

energy consumed by a 1 kW device running continuously for one hour.

$$\begin{aligned}
 E &= 1 \text{ kW-hr} \\
 \Rightarrow E &= 10^3 \text{ W} \times 1 \text{ hr} \\
 &= 1000 \text{ W} \times 3600 \text{ s} \\
 &= 3,600,000 \text{ Ws} \\
 &= 3,600,000 \frac{\text{J}}{\text{s}} \quad \left(\because 1 \text{ W} = \frac{1 \text{ J}}{1 \text{ s}} \right)
 \end{aligned}$$

$$E = 3.6 \times 10^6 \text{ J}$$

Circuit Components

		
Wires and Connections	Cell Battery	Fuse
		
Earth / Ground	Lamp	Switch Open Switch Closed
		
Capacitor	Heating Element	Fixed Resistor Variable Resistor

Circuit Components' Symbols

a. Wires and Connectors:

Wires and connectors are used to provide a path for the flow of current from one part of the circuit to another.

A blob shows that the wires are connected and a bridge shows that the intersecting wires are not connected.

b. Power Supply

Power supply is the source of electrical energy to the circuit, such as a cell and battery.

c. Fuse:

Fuse is a safety device which blows (melts) if the current exceeds the rated value.

d. Earth (Ground):

Earth is a zero volt connection of a power supply and used for safety purpose.

e. Lamp:

Lamp is a device which converts electrical energy into light.

f. Switch:

Switch allows or blocks the flow of current.

g. Heater:

Heater is a device which converts electrical energy into heat.

h. Resistor:

Resistor is a device which provides specific resistance to the current in a circuit.

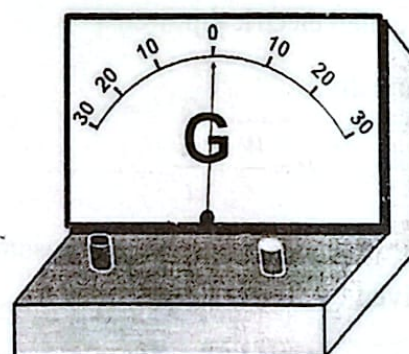
i. Capacitor:

A capacitor is a device which stores electrical energy. It is also used with resistor in timing circuit.

Electrical Measuring Instruments

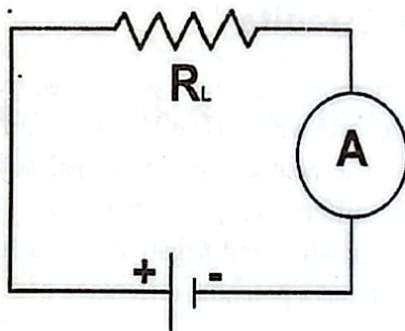
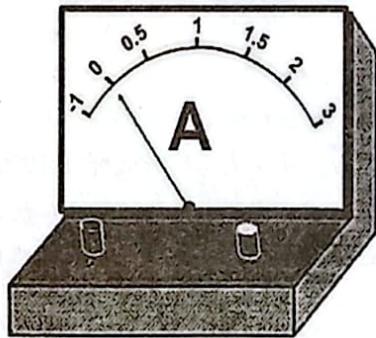
Galvanometer:

Galvanometer is an instrument used to detect current or indicate potential difference between two points. Galvanometer is a very sensitive device that is capable of detecting very small currents and voltages.

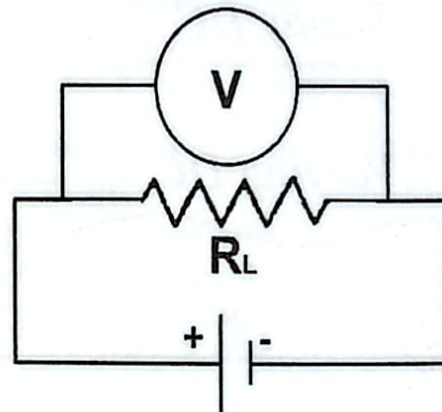
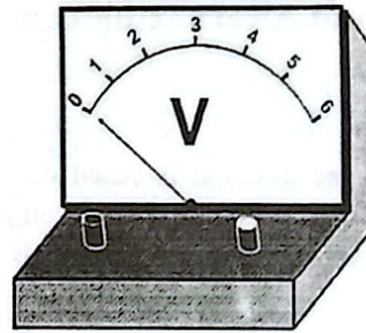


Ammeter:

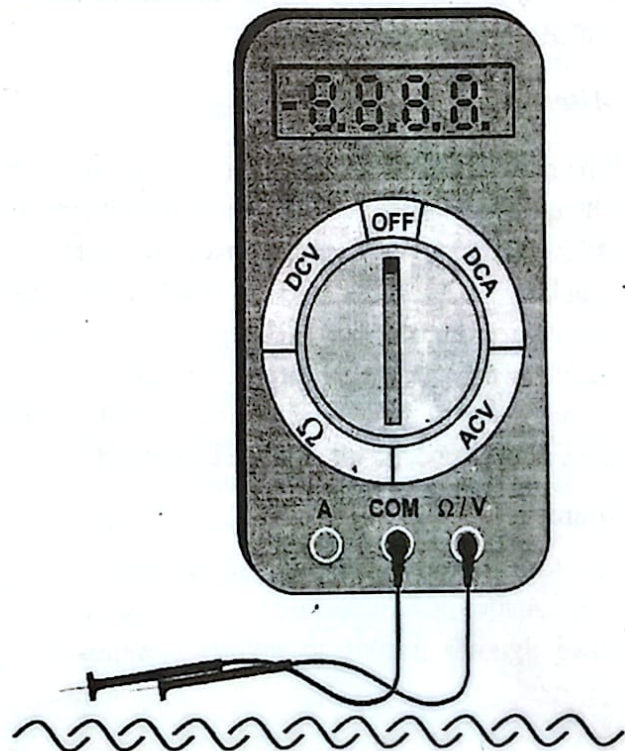
Ammeter is an instrument used to measure current. The ammeters must be connected in series so that all current through the circuit passes through it. For this purpose, they are designed to have very low resistance, so that they disturb the current to be measured as little as possible.

**Voltmeter:**

Voltmeter is an instrument used to measure potential difference (voltage). Voltmeters are connected in parallel with the component across which potential difference is to be measured. Voltmeters are designed to have very high resistance so that they disturb the current passing through the component as little as possible. Thus, they have negligible effect on the potential difference that is to be measured.

**Multimeter:**

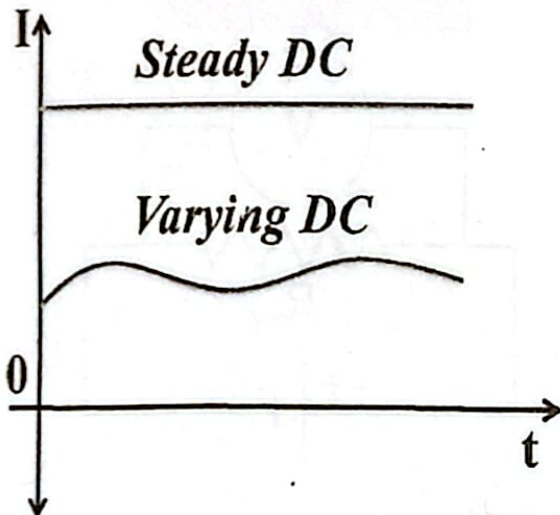
Multimeter is an instrument used for multiple measurements. It can be switched between functioning as ammeter, voltmeter and ohmmeter. So they are also called AVOMETER. 'A' stands for Ammeter, 'V' stands for Voltmeter and 'O' stands for Ohmmeter.



Direct and Alternating Current

Direct Current:

The current which is comprised of charges flowing in one direction is called direct current (DC). The sources of DC such as cell or battery has fixed positive and negative terminals.



Steady DC: The direct current whose magnitude does not change as time passes is called steady direct current.

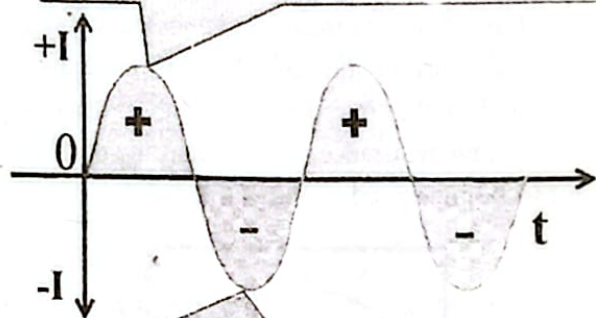
Varying DC: The direct current whose magnitude changes as time passes (i.e. it has fluctuations) is called varying direct current.

Alternating Current (AC):

The current whose magnitude as well as direction changes regularly is called alternating current. In AC, the charge flow reverses its direction regularly. AC sources have no fixed positive and negative terminals, but exchange regularly. As a result, when an AC source is connected to a circuit, current first flows in one direction and then in the opposite direction. The symbol for AC source is 

Positive Half Cycle

The magnitude of current increases in one direction from zero to its peak value and then decreases back to zero.



Negative Half Cycle

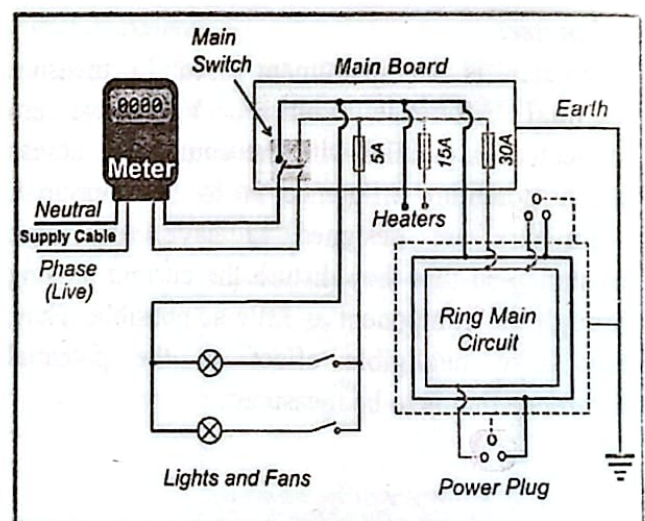
The magnitude of current increases in opposite direction from zero to its peak value and then decreases back to zero.



House Circuits

The electricity to our homes is supplied by a cable containing two wires: Live 'L' wire and Neutral 'N' wire. The neutral wire is earthed and has no potential difference, and the live wire is alternately positive and negative with a frequency of 50 Hz and at a potential difference of 220 V.

Following figure shows a typical house circuit.



Parallel Circuitry:

Every appliance in a house is connected in parallel, which has the following advantages.

- Each appliance receives the same voltage of 220 V.
- Each appliance can be turned on and off independently. If one burns, the other can still be operated.

Switches and Fuses:

The switches and fuses are connected only in live wire because if we turn off an appliance or a fuse burns, the live wire disconnects, and the appliance is no more live. Thus, we can avoid electric shocks.

Ring Main Circuit:

Ring main circuit consists of two thicker wires (live wire and neutral wire) running in a complete ring and has a high current rated fuse (~30 A).

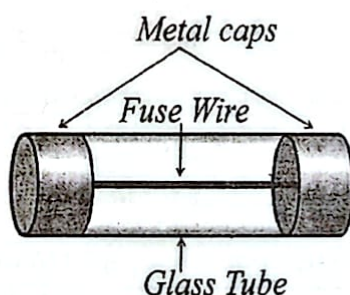
Power sockets are connected to the ring main circuit via relatively thinner wires. It is beneficial to have a ring circuit in our houses because we can operate heavy appliances by relatively thinner wires.

Electrical Safety in Household Electricity

The electricity main supply to our houses is 220 V, which is hazardous. So, we should install fuses and earth connection for safe use of electricity.

Fuses and Circuit Breakers:

Fuse consists of a thin wire of metal having low melting point that is enclosed in a glass tube with metal caps fixed at both ends, as shown in the figure.



When an excessive current passes through the wire, it gets hot and melts. As a result, the live

wire disconnects, thus preventing any damage to the appliance.

Nowadays, circuit breakers are used instead of fuses, because they operate much faster than fuses and easy to reset.

Earthing:

A thick wire with almost zero resistance is used as earth wire which is connected either to a metal pipe or to an earth connection in the supply cable. The earth wire is connected to the metal case of the appliance. It is used to avoid electric shocks.

For example, if the metal casing of the appliance touches the live wire, a large current will flow to the earth and the fuse will blow. Otherwise, the body will become live and anybody touching it will receive an electric shock, which can be fatal.

Dangers of Electricity

A. Electric Shock:

An electric shock means the flow of current through a person's body to the earth. An electric shock occurs due to a damaged insulation or faulty wiring.

The typical resistance of dry skin is about $10,000\Omega$ and that of the wet skin is about 1000Ω . If a person touches a wire that is at 240 V, a current of 24 mA will pass through a dry skin and 240 mA will pass through a wet skin.

The severity of an electric shock depends on the following factors.

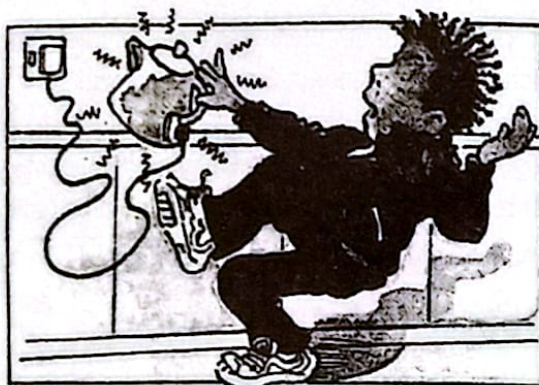
- Size of the current: The larger the current the stronger will be the shock and vice-versa.
- Length of time: The longer the time for which the electric shock acts, the more severe will be the electric shock.
- The path of the current: Some parts of the body are more vulnerable than others. For example, a current of 100mA through heart can be fatal.

How to avoid an electric shock?

- Switch off the appliance before starting repairs.
- Use plugs that have an earth pin and a cord-grip.
- Do not allow appliances or cables to come in contact with water.
- Avoid long cable trailing across a room because the insulation can be damaged.



CONCEPT



This electric kettle does not have a proper earth connection to its metal casing. So, when, touched, it gives an electric shock.

B. Fire Risks:

Wires become hot when they carry electrical currents. If the current through a wire is large enough, the wire overheats and can catch fire. To avoid the risk of catching fire, the following precautions should be taken.

- Use plugs that have a correct fuse.
- Do not operate too many appliances from a socket (or an extension box).
- Do not overload circuits by using too many adapters.
- Use thicker wires for heavy appliances.
- Avoid damage insulation or faulty wiring because a large current from the damage insulation through flammable material to earth can start fire.

EXERCISE

Multiple Choice Questions

1	Batteries are rated with unit 'ampere-hour', it is the unit of	A Charge	B Current
		C Power	D Energy
2	When connected to a battery, a lightbulb glows brightly. If the battery is reversed and reconnected to the bulb, the bulb will glow	A Brighter	B Dimmer
		C With the same brightness	D Fuse
3	The resistance of wire will decrease by increasing	A Temperature	B Length
		C Diameter	D Both (A) & (B)
4	The wire made from which of the following material is a conductor	A Glass	B Rubber
		C Silver	D Silk
5	The current which reverses direction after regular interval of time is	A DC	B AC
		C Conventional current	D Both (A) & (B)
6	Electricity main supply meters measures it in units of 'kilowatt-hour': it is the unit of	A Charge	B Current
		C Power	D Energy
7	The device that is used to protect a circuit against overload is	A Heater	B Fuse
		C Lamp	D All of these
8	Which of the following represent one ohm	A VA^{-1}	B Js^{-1}
		C WA^{-1}	D JC^{-1}
9	Two resistances of 1 ohm are connected in parallel, the equivalent resistance is	A 1Ω	B 1.5Ω
		C 1Ω	D 0.5Ω
10	$1\text{ kWh} =$	A $3600W$	B $1000J$
		C $3.6 \times 10^6 J$	D 0.36 hrs

Conceptual Questions

1. As water is made of atoms having protons (charge $+e$) and electrons (charge $-e$), does the water flowing through pipe carry an electric current? Explain.

Ans. An electric current is a flow of the electric charge. As the molecules of water are neutral, that is, they contain the neutral atoms of hydrogen and oxygen (having equal number of protons and electrons), so the water flowing through pipe does not carry an electric current.

2. A car has two headlights, when the filament in one head light burns out, the other headlight stays on. Are the headlights connected in series or in parallel?

Ans. The headlights of a car are connected in parallel because the parallel circuit provides two separate paths for the two headlights. It means that each headlight has its own path for the flow of current. Therefore, if the filament in one headlight burns out and the current through the path stops, it does not affect the current through the other path and the other headlight stays on.

On the other hand, series circuit provides a single path for all the components. Thus, if the headlights were connected in series, the circuit would be opened by the burnt-out filament and the other headlight would not stay on.

3. Qurat-ul-Ain needs a 100Ω resistor for a circuit, but she only has a box of 300Ω resistors. What can she do?

Ans. If she connects the resistors in parallel, then the equivalent resistance can be found as:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Here, $R_1 = R_2 = R_3 = 300\Omega$

$$\frac{1}{R_{eq}} = \frac{1}{300} + \frac{1}{300} + \frac{1}{300}$$

$$\frac{1}{R_{eq}} = \frac{1+1+1}{300} = \frac{3}{300}$$

$$R_{eq} = \frac{300}{3} = 100\Omega$$

Thus, she can get an equivalent resistance of 100Ω by connecting the three resistors of 300Ω in parallel combination.

4. A number of light bulbs are connected to a single power outlet. Will they provide more illumination when connected in series or in parallel? Why?

Ans. As we know that in parallel circuit, each circuit component gets full potential difference supplied by the power supply. While in series circuit, the supplied potential difference is divided among all the components. Therefore, if the light bulbs are connected in parallel, they will provide more illumination by using the full potential difference supplied by the power outlet.

5. Explain why light bulbs almost always burn out just as they are turned on and not after they have been on for some time.

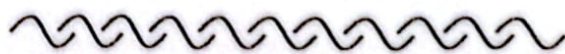
Ans. The light bulbs almost always burn out just as they are turned on because of *inrush current*. The inrush current is the high instantaneous input current drawn by an electrical device when first turned on. It is due to the fact that initially the tungsten filament (conductor) is cold, and the inrush current is quite high. Due to this high current, more power is dissipated in the form of heat and the filament burns out.

Once they have been shiny for some time, the filament heats up and current passing through it decreases and the filament is unlikely to burn out.

6. Explain why is it possible for birds to perch safely on high tension wires without being electrocuted?

Ans. It is possible for birds to perch safely on high voltage wires without being electrocuted because they are not in direct or indirect contact with ground in order to provide a closed path for the current to flow through their bodies.

In other words, they are at the same potential as that of the high voltage wire. Due to zero potential difference, no current flows through their bodies and they are not electrocuted.



7. An electrician working on 'live' circuits wears insulated shoes and keeps one hand behind his or her back. Why?

Ans. Electric shock may be sometimes fatal. So, for safety purposes, an electrician while working on live circuits wears insulated shoes and keeps one hand behind his/her back. The insulated shoes do not allow current to flow through his/her body to the ground. While, keeping one hand behind prevents him/her from touching ground or other conductive materials that are in contact with ground.



8. Explain why it is dangerous to turn on a lightbulb when you are in a bath tub.

Ans. Since impure water conducts electricity and also the hands are wet while taking bath. Due to these reasons, it is dangerous for a person to turn on a lightbulb and can get an electric shock, when he/she is in a bath tub. If he/she touches the switch with wet hands, there may be a possibility to provide a path for the current to pass through his/her body to the impure water and then to the ground.



9. Why circuit breaker, fuses and switches are installed to 'live wires'?

Ans. Circuit breakers and fuses are used to protect the electric circuit from damage caused by the flow of large current when there is a fault or short circuit. While switches are used to switch on and off the circuit. They must be installed in the live wire to ensure that they do not allow the high voltage to reach the user or surroundings, when the circuit breaker trips, the fuse burns out or the switch is off.

Numerical Questions

1. A small electric heater has a resistance of 15 ohms when the current in it is 2 amperes. What voltage is required to produce this current?

Given data :

Resistance ' R ' = 15 Ω

Current ' I ' = 2 A

Required :

Voltage ' V ' = ?

Solution :

As we know that

$$V = IR \quad (\text{Put the values})$$

$$V = 2 \times 15$$

$$V = 30V$$



2. If a potential difference of 10V is maintained across a 1 m length of the Nichrome wire having resistance of 3.1 Ω what is the current in the wire?

Given data :

Potential difference ' V ' = 10V

Length ' L ' = 1m

Resistance ' R ' = 3.1 Ω

Required :

Current ' I ' = ?

Solution :

As we know that

$$V = IR$$

$$\Rightarrow I = \frac{V}{R} \quad (\text{Put the values})$$

$$I = \frac{10}{3.1}$$

$$I = 3.2A$$



3. What resistor would have a 15 mA current if connected across the terminals of a 9.0V battery?

Given data :

Current ' I ' = 15mA = 15×10^{-3} A

Voltage ' V ' = 9.0V

Required :

Resistance ' R ' = ?

Solution :

As we know that

$$V = IR$$

$$\Rightarrow R = \frac{V}{I} \quad (\text{Put the values})$$

$$R = \frac{9}{15 \times 10^{-3}}$$

$$R = \frac{9 \times 10^3}{15}$$

$$R = 600\Omega$$



4. Consider a circuit with three resistors $R_1 = 250.0\Omega$, $R_2 = 150.0\Omega$, $R_3 = 350.0\Omega$ connected in parallel with a 24.0V batter. Find the total current supplied by the battery.

Given data :

Resistor ' R_1 ' = 250.0 Ω

Resistor ' R_2 ' = 150.0 Ω

Resistor ' R_3 ' = 350.0 Ω

Voltage ' V ' = 24.0V

Given that the combination is parallel

Required :

Total current ' I ' = ?

Solution :

As we know that

$$I = \frac{V}{R_{eq}} \quad (1)$$

We also know that

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

(Put the values)

$$\frac{1}{R_{eq}} = \frac{1}{250} + \frac{1}{150} + \frac{1}{350}$$

$$\frac{1}{R_{eq}} = \frac{21 + 35 + 15}{5250}$$

$$\frac{1}{R_{eq}} = \frac{71}{5250}$$

$$\Rightarrow R_{eq} = \frac{5250}{71}$$

$$R_{eq} = 73.9\Omega$$

(Put the values in equ. 1)

$$(1) \Rightarrow I = \frac{24.0}{73.9}$$

$$I = 0.3A$$



5. An electric hair dryer is rated at 1875 watts when operating on 120 volts. What is the current flowing through it? If the hair dryer is used for 3 minutes, how much energy does it consume?

Given data :

Power ' P ' = 1,875W

voltage ' V ' = 120V

Time ' t ' = 3 min = $3 \times 60s = 180s$

Required :

a) Current ' I ' = ?

b) Electrical energy ' E ' = ?

Solution :

a) As we know that

$$P = IV$$

$$\Rightarrow I = \frac{P}{V} \quad (\text{Put the values})$$

$$I = \frac{1875}{120}$$

$$I = 15.6A$$

b) We also know that

$$P = \frac{E}{t}$$

$$\Rightarrow E = Pt \quad (\text{Put the values})$$

$$E = 1875 \times 180$$

$$E = 337,500J$$



6. A battery with an emf of 12V is connected to a 545 Ω resistor. How much energy is dissipated in the resistor in 65 s?

Given data :

Voltage (emf) ' V ' = 12V

Resistance ' R ' = 545 Ω

Time ' t ' = 65s

Required :

Energy ' E ' = ?

Solution :

As we know that

$$E = \frac{V^2}{R} t \quad (\text{Put the values})$$

$$E = \frac{12^2}{545} \times 65$$

$$E = 17J$$



7. If the unit of electricity costs 8.11 Rs/kWh, what is cost of running two 160W fans and four 100W lightbulbs for 6 hours in a school?

Given data :

Cost of 1kWh = Rs. 8.11

Power of two fans ' P_f ' = $2 \times 160W$

$$= 320W = 0.32kW$$

Power of two bulbs ' P_b ' = $2 \times 100W$

$$= 200W = 0.2kW$$

Time ' t ' = 6 hrs

Required :

Total cost = ?

Solution :

Total cost = $E_t(kWh) \times \text{Rs. } 8.11 \dots \dots \dots (1)$

Total energy ' E_t ' = $E_f + E_b \dots \dots \dots (2)$

As we know that

$$P = \frac{E}{t}$$

$$\Rightarrow E = Pt$$

$$\Rightarrow E_f = P_f \times t \quad (\text{Put the values})$$

$$E_f = 0.32kW \times 6h$$

$$E_f = 1.92kWh$$

Similarly

$$E_b = P_b \times t \quad (\text{Put the values})$$

$$E_b = 0.2kW \times 6h$$

$$E_b = 1.2kWh$$

(Put the values in equ. 2)

$$(2) \Rightarrow E_t = 1.92 + 1.2$$

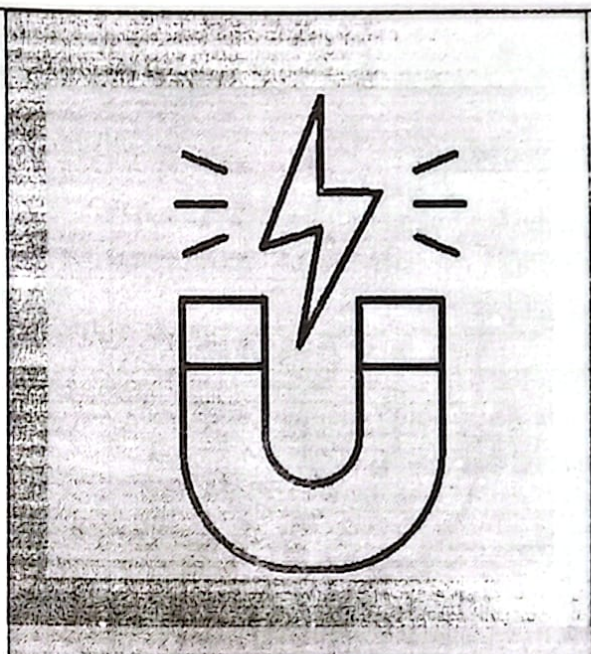
$$E_t = 3.12kWh$$

(Put the values in equ. 1)

$$(1) \Rightarrow \text{Total cost} = 3.12 \times \text{Rs. } 8.22$$

$$\text{Total cost} = \text{Rs. } 25.3$$





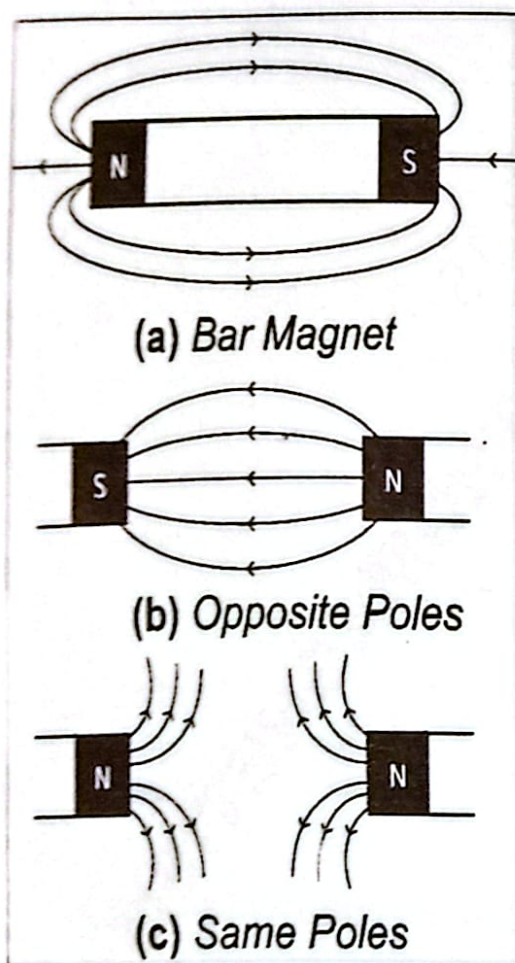
UNIT 15
ELECTROMAGNETISM

Magnetic Field

The region around a magnet in which other magnetic materials experience its magnetic force is called magnetic field.

Permanent Magnet:

The magnet that has a fixed magnetic field is called permanent magnet. The magnetic field patterns of permanent magnets are shown in the figure.



Electromagnet:

The magnet whose magnetic field depends upon the current passing through it and the number of turns is called electromagnet.

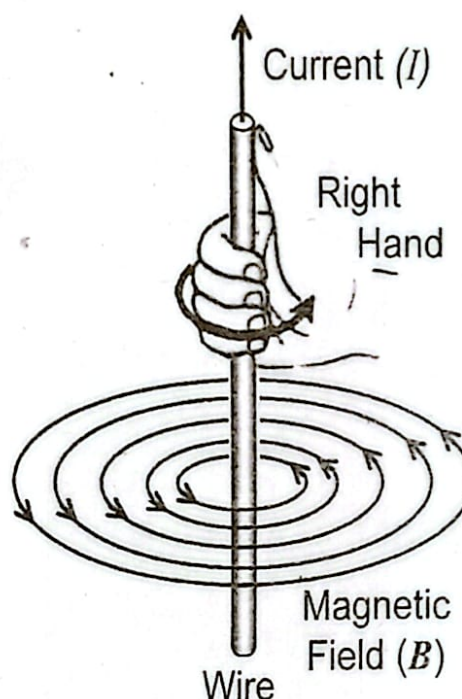
Magnetic Effect of a Steady Current

A stationary charge is surrounded by an electric field while a moving charge is surrounded by both electric field and magnetic field. As we know that current consists of moving charges,

so a wire carrying current is surrounded by a magnetic field which can be detected by bringing a compass needle close to the wire.

Magnetic Field due to a straight steady current carrying wire:

As we know that a moving charge is surrounded by both electric field and magnetic field, the moving charges which comprise the current in the straight wire produce a circular magnetic field around the wire, as shown in the figure.



The direction of the magnetic field due to a straight current carrying wire can be found by right hand rule (I).

Right Hand Rule (I):

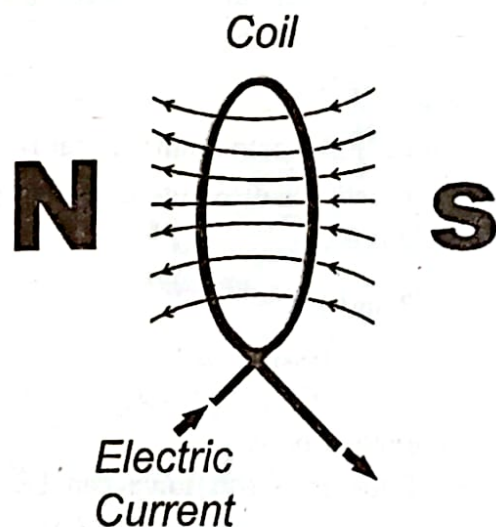
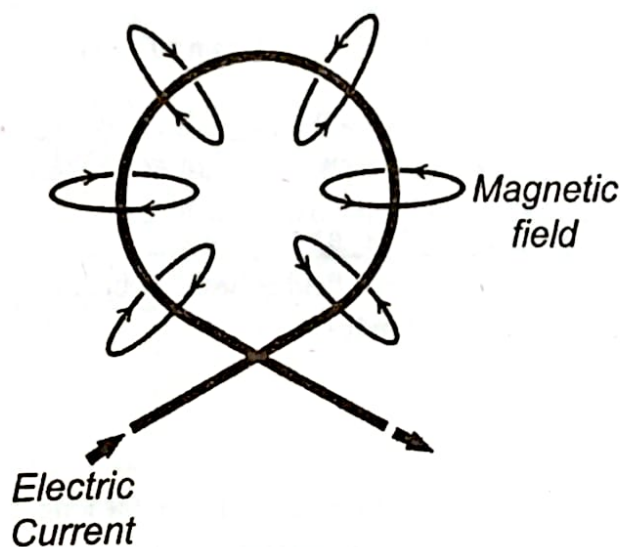
Point thumb of right hand in the direction of current and curl the fingers around the wire, the curled fingers show the direction of magnetic field due to a straight current carrying wire.

Magnetic field due to a coil:

A coil consists of a wire wrapped in one or more turns. The wire is covered with insulating material.

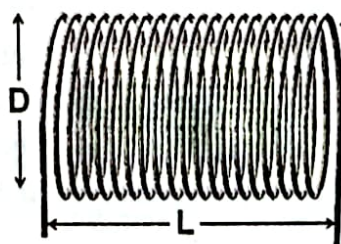


Consider a loop of steady current carrying wire. By applying the right-hand rule (I) at different points, the direction of the magnetic field is same, i.e. coming in at one side and going out of the other side. As a result, a current carrying coil acts like a bar magnet having north pole and south pole. The magnetic field of a coil is stronger inside and weaker outside the coil.



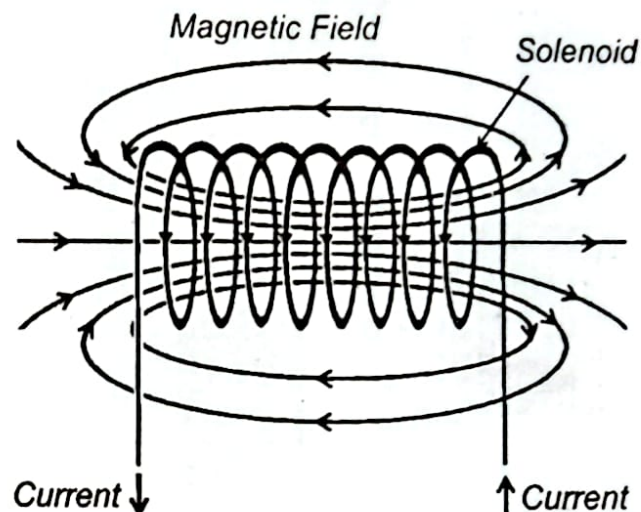
Magnetic field due to a Solenoid:

When a coil is made such that its diameter is smaller than its length ($D < L$), then it is called solenoid.



When current is passed through a solenoid, a magnetic field is produced along its axis, which

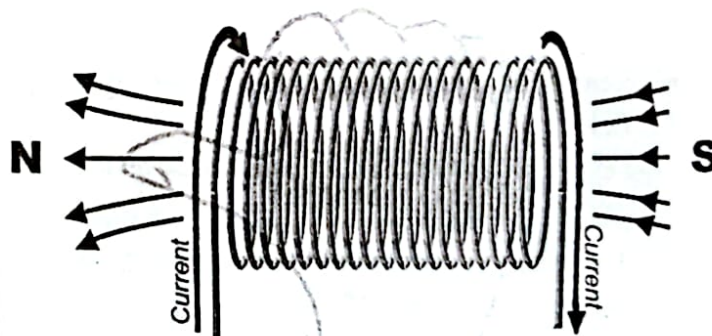
is almost uniform and strong inside the solenoid and negligible outside.



The current carrying solenoid resembles a bar magnet, i.e. it has a north pole and south pole. The direction of the magnetic field due to a solenoid can be found by right hand rule (II).

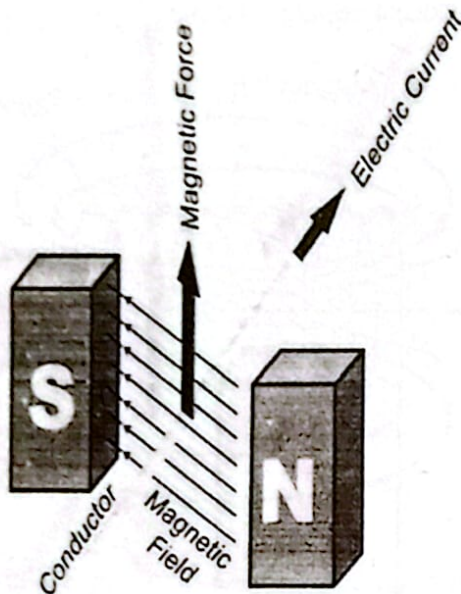
Right Hand Rule (II):

Curl the fingers of right hand in the direction of current around the solenoid. The extended thumb points in the direction of north pole.



Force on a Current Carrying Conductor in a Magnetic Field

When a current carrying conductor is placed in a magnetic field, it is acted upon by a force called magnetic field.



The magnetic force is due to the interaction between the field induced by the current carrying conductor and the external applied magnetic field.

The magnetic force ' F_B ' is directly proportional to:

- The current passing through the conductor.
i.e. $F_B \propto I$(1)
- The external applied magnetic field ' B '
i.e. $F_B \propto B$(2)
- Length of the conductor in the magnetic field.
i.e. $F_B \propto L$(3)
- The sine of angle between direction of current and magnetic field.
i.e. $F_B \propto \sin\theta$(4)

Combining relations (1), (2), (3) and (4), we get

$$F_B \propto ILB \sin\theta$$

$$\Rightarrow F_B = k I L B \sin\theta$$

Here ' k ' is the constant of proportionality. In SI units, $k = 1$. So, the magnitude of force experienced by a current carrying conductor in a magnetic field is given by

$$F_B = I L B \sin\theta \text{.....(5)}$$

Maximum Force:

The magnetic force ' F_B ' is maximum when the angle ' θ ' between direction of current and magnetic field is 90° .

$$\begin{aligned} F_B &= I L B \sin(90^\circ) \\ \text{i.e. } F_B &= I L B \quad (\because \sin 90^\circ = 1) \\ \Rightarrow B &= \frac{F_B}{IL} \text{.....(6)} \end{aligned}$$

Unit of Magnetic field ' B '

The SI unit of magnetic field is 'tesla', which is defined from equation (6) as

$$1T = \frac{1N}{1A \times 1m}$$

The magnetic field strength is 1T if a 1m long conductor carrying 1A current experiences a maximum magnetic force of 1N.

Minimum Force:

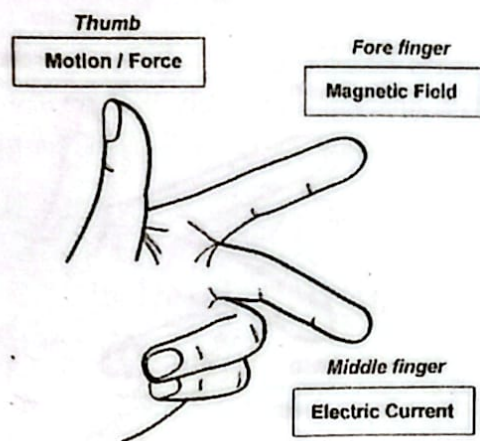
The magnetic force ' F_B ' is minimum (i.e. zero) when the angle ' θ ' between direction of current and magnetic field is 0° .

$$\begin{aligned} F_B &= I L B \sin(0^\circ) \\ \text{i.e. } F_B &= 0 \quad (\because \sin 0^\circ = 0) \end{aligned}$$

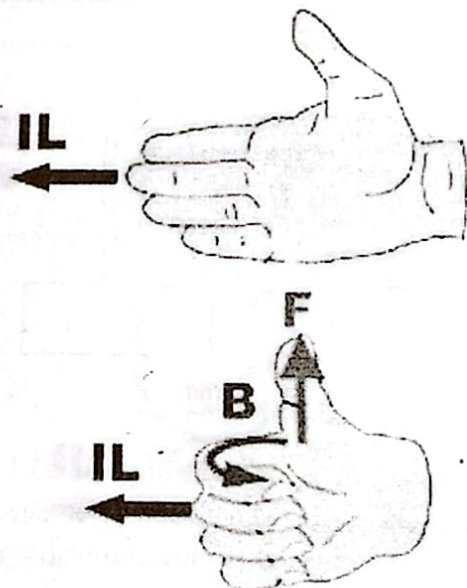
Direction of Magnetic Force:

The direction of the magnetic force can be found by:

Fleming Left-Hand Rule: Stretch the thumb and first two fingers of left hand such that they are perpendicular to each other. Point the first finger in the direction of magnetic field and the second finger in the direction of current. The thumb gives the direction of the magnetic force.



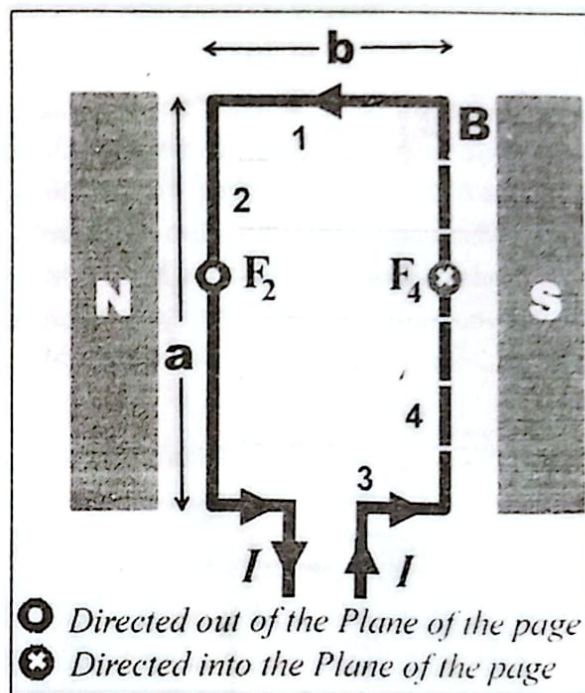
Right-Hand Rule (III): Point the fingers of right hand in the direction of current first and then bend them in the direction of magnetic field. The stretched thumb gives the direction of the magnetic field.



Torque on a Current Carrying Coil in a magnetic field

When a current carrying coil is placed in a uniform magnetic field, it is acted upon by torque.

Consider a rectangular coil of length 'a' and width 'b' placed between two opposite magnetic poles as shown in the figure.



As shown in the figure, sides 1 and 3 experience no magnetic force because they are parallel to the magnetic field (i.e. $\theta = 0$).

$$F_1 = F_3 = ILB \sin 0^\circ$$

$$\Rightarrow F_1 = F_3 = 0 \quad (\because \sin 0^\circ = 0)$$

Sides 2 and 4 experience maximum magnetic force because they are perpendicular to the magnetic field (i.e. $\theta = 90^\circ$).

$$F_2 = F_4 = ILB \sin 90^\circ$$

$$\Rightarrow F_2 = F_4 = ILB \quad (\because \sin 90^\circ = 1)$$

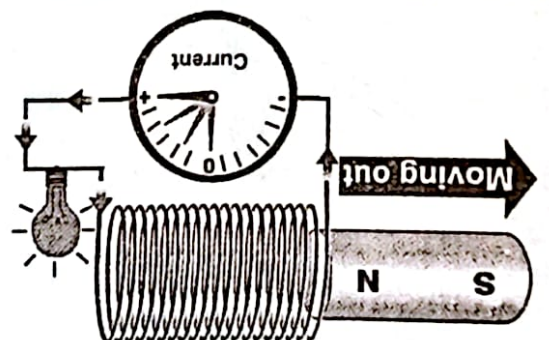
Since the forces F_2 and F_4 are equal in magnitude and opposite in direction, so they make a couple which rotates the coil.

DC Motor

Electric motor is a device that converts electrical energy into mechanical energy.

Working Principle: DC motor works on the principle that a current carrying coil in a magnetic field experiences torque.

other direction. It means that the induced current is AC.



Similar effects can be observed if the coil is moved either toward or away from a stationary magnet.

Factors affecting the magnitude of induced emf:

The magnitude of induced emf depends upon:

- The number of turns in the coil: It is directly proportional to the number of turns in the coil.

- Strength of the magnetic of the magnetic field: It is directly proportional to the strength of the changing magnetic field.

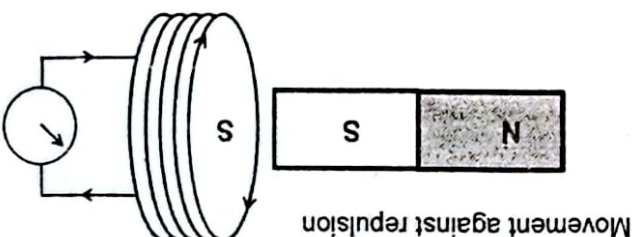
- Relative motion of the magnet and the coil: It is directly proportional to the speed at which the magnet and the coil are moved toward and away from each other.

Direction of the induced emf and conservation of energy:

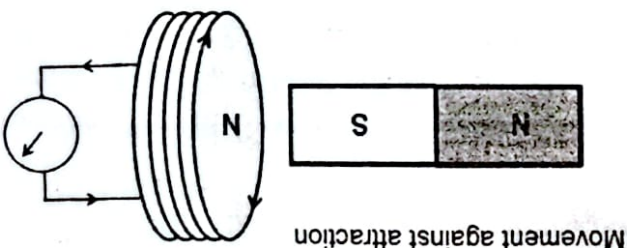
The emf induces in such a way that the induced current will flow in such a direction so as to oppose the cause that produces it.

It is due the fact that the induced current produces its own magnetic field whose direction is always such that it tries to prevent the magnetic field from changing.

Explanation: Consider a bar magnet with its south pole pushed toward a coil, due to which the magnetic field through the coil increases. To oppose the increase in the magnetic field, the induced current in the coil produces its own magnetic field with south pole pointing the south pole of the bar magnet.



Now consider the bar magnet pulled away from the coil due to which the magnetic field through the coil decreases. To oppose the decrease in the magnetic field, the induced current in the coil produces its own magnetic field with north pole pointing the south pole of the magnet.



The above activity shows that the motion of the magnet (i.e. the change in magnetic field which causes the induced emf) is always opposed by the magnetic field generated by the induced current.

The generation of electrical energy by electromagnetic induction is consistent with the law of conservation of energy, i.e. we have to do work to overcome the opposition. It means that the mechanical energy spent in overcoming the opposition is converted into electrical energy.

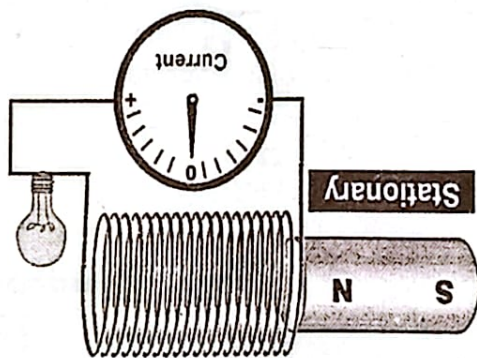
previously left side (i.e. right side) is acted upon by upward force. In this way the current reverses the direction after every half rotation and the coil continues its rotation in the same direction.

Electromagnetic Induction

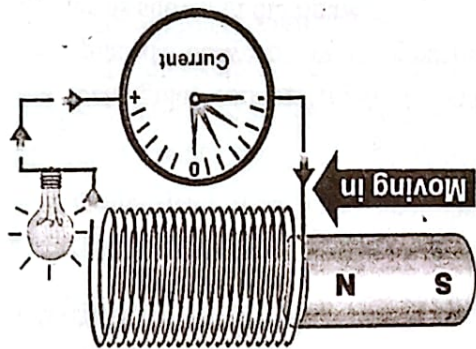
When magnetic field through a conductor is changed, an emf induces across the conductor. This phenomenon is called electromagnetic induction. The current due electromagnetic induction is called induced current.

Explanation:

Consider a coil connected to a galvanometer. When the magnet and the coil are stationary with respect to each other, the galvanometer shows no deflection.

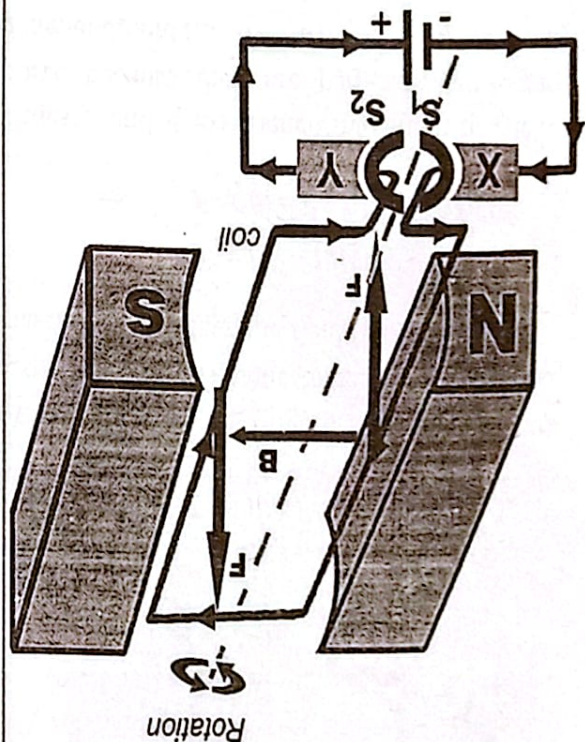


But if the magnet is moved either toward or away from the coil, the galvanometer shows deflection. If the magnet is moved towards the coil the galvanometer shows deflection in one direction.



Whereas, if the magnet is moved away from the coil, the galvanometer shows deflection in the

Construction: A DC motor consists of a rectangular coil wound around soft iron core which is mounted on a spindle and placed between opposite poles of permanent magnet. The coil and the core together are called *armature*. The core intensifies the magnetic field. The ends of the coil are attached to a split ring called commutator. The commutator is connected to the power supply via a pair of brushes.



Working: As shown in the figure, S_1 and S_2 are initially in contact with brushes X and Y, respectively. The current enters the coil through S_1 and leaves through S_2 . In this case, the coil rotates anticlockwise due to the equal and opposite forces on both sides.

When the coil becomes vertical, the gaps in the commutator align with the brushes and the current through the coil stops. But, due to inertia the rotation of the coil does not stop.

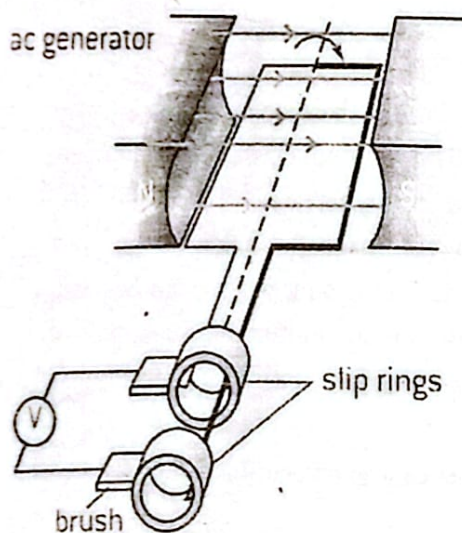
As the coil continues its rotation, S_1 comes in contact with brush Y and S_2 with brush X and the current reverses the direction through the coil. Now the previously right side (i.e. left side) is acted upon by downward force and the

AC Generator

A device which converts mechanical energy into electrical energy is called electric generator.

Working Principle: The AC generator works on the principle of electromagnetic induction.

Construction: An AC generator consists of a coil mounted on a rotar shaft and placed between opposite poles of permanent magnet. The ends of the coil are connected to two slip rings which are in contact with brushes. The output is taken from the brushes.



Working: When the coil is rotated inside the magnetic field, the magnetic field through the coil changes. As a result, emf induces across the ends of the coil. Since the magnitude and direction of the induced emf changes, an AC current induces in the coil. Therefore, the generator is called AC generator.

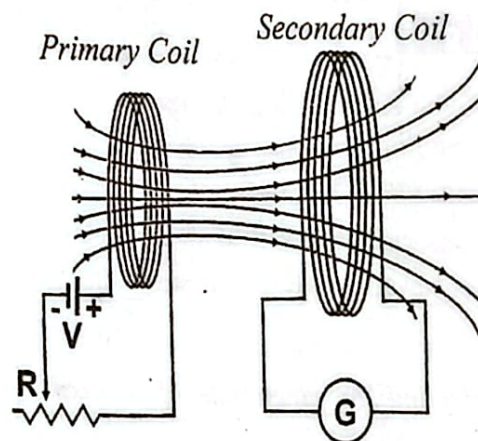
In a DC generator, the slip rings are replaced by a commutator (split ring). A DC generator produces current whose magnitude changes continuously, but the direction does not change.



Mutual Induction

The phenomenon in which an emf induces in one coil due to changing current in another nearby coil.

Consider two coils placed near to each other such that the magnetic field generated by the primary coil (to which battery is connected) links the secondary coil (to which galvanometer is connected), as shown in the figure.



When the current through primary coil is changed by changing the value of the variable resistor, the magnetic field generated by it also changes. Due to which the magnetic field through the secondary coil also changes and an emf induces in it. The emf induced in the secondary coil (called mutually induced emf) is directly proportional to the rate at which the current is changed in the primary coil.

$$\epsilon_s \propto -\frac{\Delta I_p}{\Delta t} \dots \dots \dots (1)$$

The negative sign shows that the induced current is in opposite direction to the original current flow.

$$(1) \Rightarrow \epsilon_s = -M \frac{\Delta I_p}{\Delta t} \dots \dots \dots (2)$$

Where 'M' is the constant of proportionality known as coefficient of mutual induction and is given by

$$(2) \Rightarrow M = \frac{\epsilon_s}{\Delta I_p / \Delta t} \dots \dots \dots (3)$$

The SI unit of coefficient of mutual induction is henry 'H' which can be defined from equation (3) as:

$$(3) \Rightarrow 1H = \frac{1V}{1A/s} = \frac{1V \times 1s}{1A}$$

The mutual inductance of two coils is $1H$, if the current in the primary coil changes at the rate of $1A/s$ and the emf induced in the secondary coil is $1V$.



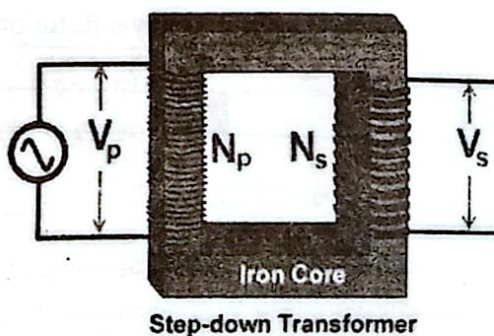
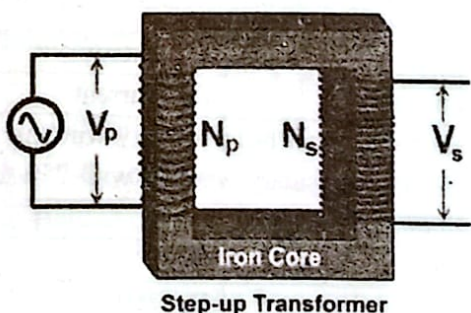
Transformer

A transformer is a device which is used to increase or decrease an AC voltage or current level.

Working Principle: Transformers work on the principle of mutual induction.

Construction: A transformer consists of two coils: *primary coil* (to which power is supplied) and *secondary coil* (from which power is drawn). They are electrically insulated from each other and wound on the same core. The core is made of soft iron which intensifies the magnetic field and reduces the magnetic flux leakage.

Step-up and Step-down Transformers:



If the number of turns in the primary coil is N_p , the number of turns in secondary coil is N_s , the input (primary) voltage is V_p and the output (secondary) voltage is V_s , then

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

In the above equation, N_s / N_p is called *turns ratio* of the transformer. If the ratio ' N_s / N_p ' for a transformer is greater than 1, then it is called *step-up transformer*. While, if the ratio ' N_s / N_p ' for a transformer is smaller than 1, then it is called *step-down transformer*.

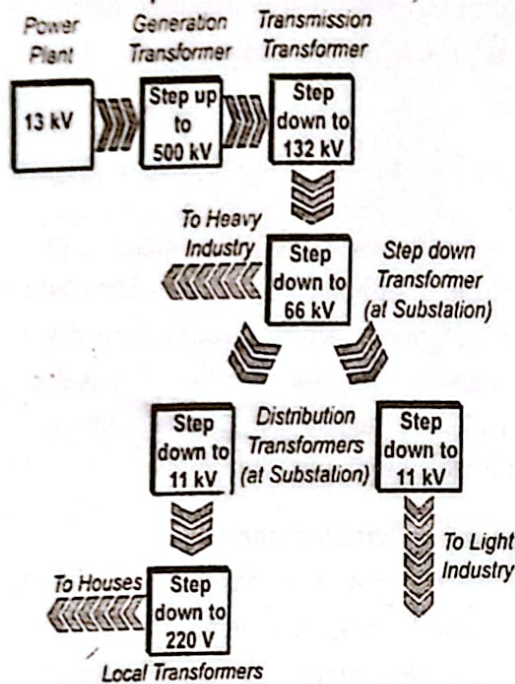
Purpose of Transformers:

When electric power is transmitted through transmission lines, there is some loss of power due to resistive heating. The higher the current, the higher will be the loss. As we know that

$$P = IV$$

According to the equation, for a constant value of power, if the voltage is increased then the required current will decrease. Due to this fact, electric power companies use step-up transformers to step-up the voltage in order to reduce the current.

- A power plant produces a voltage of 13,000 V which is raised to 500,000 V by step-up transformer.
- This high-voltage power is then transmitted to the substations through long-distance transmission lines.
- At the substation, the voltage is reduced to 1100 V using step-down transformers and transmit it for domestic use.
- At towns or villages, step-down transformers (pole transformers) further reduce the voltage to 240 V for domestic use.



EXERCISE

Multiple Choice Questions

- A current carrying wire in which current flow in northward direction is deflected towards the east by a magnetic force. The direction of the magnetic field is

A	Straight up	B	Straight down
C	South	D	West
- Which derived unit is equivalent to tesla T?

A	Nm/A	B	NA/m
C	N/Am	D	Am/N
- The unit of inductance, the henry, is equivalent to

A	Vs/A	B	VA/m
C	As/V	D	V/A
- When the speed at which magnet is moved through a coil is increased, the induced voltage

A	Increases	B	Remains the same
C	Decreases	D	Goes to 0
- Slip rings are part of

A	DC motor	B	AC generator
C	Transformer	D	magnet
- A transformer is used for

A	Both DC & AC	B	AC voltages
C	DC voltages	D	Farming
- A step-up transformer increases

A	Power	B	Energy
C	Voltage	D	Current
- A certain transformer has a primary winding with 500 turns and secondary winding with 250 turns. The turn ratio is

A	0.5	B	2
C	250	D	750
- If the turns ratio is 5, the secondary voltage is greater than the primary voltage by a factor of

A	0.2	B	0.5
C	2.5	D	5

Conceptual Questions

1. Differentiate between electric and magnetic fields.

Electric Field	Magnetic Field
1. Electric field is the region around a charge where other charged bodies experience its electric force.	1. Magnetic field is the region around a magnet where other magnetic materials experience its magnetic force.
2. The source of electric field is stationary as well as moving charge.	2. The source of magnetic field is only moving charge.
3. Electric field can change both the speed and direction of moving charged particle.	3. Magnetic field can change only the direction of moving charged particle.
4. Electric monopole is possible (i.e. only positive or negative charge can exist).	4. Magnetic monopole is not possible (i.e. a magnet has always both the north and south poles).
5. The SI unit of electric field is N/C.	5. The SI unit of magnetic field is Tesla

2. Can an electron at rest be set into motion with a magnetic field?

Ans. The magnetic force on a charged particle is given by,

$$F_m = qvB\sin\theta \dots\dots\dots (1)$$

Where, q is the charge on the particle, v is the speed of the particle, B is the magnitude of the

magnetic field and θ is the angle at which the particle enters the magnetic field.

In the present case, the electron is at rest i.e. $v=0$, so equation (1) becomes:

$$F_m = q(0)B\sin\theta$$

$$F_m = 0$$

Which shows that an electron at rest does not experience any magnetic force and cannot be set into motion with a magnetic field.



3. Which is more likely to show deflection in compass needle, AC or DC current? Explain.

Ans. When an electric current passes through a wire, a magnetic field is produced around it. When the direction of current is reversed, the direction of the induced magnetic field also reverses.

In case of DC current, the induced magnetic field will have same direction and the compass needle will align with the induced magnetic field. Thus, it will show deflection. While, in case of AC current, the magnetic field will continuously reverse its direction very rapidly. Due to which the compass needle will be unable to respond to such continuously and rapidly varying magnetic field. That is, the compass needle will not show any deflection.



4. A constant magnetic field is applied to a current carrying conductor. What angle should the wire make with the field for the force to be (a) maximum, (b) minimum?

Ans. The magnetic force on a current carrying wire placed in a magnetic field is given by

$$F_M = BIL \sin \theta \dots\dots\dots (1)$$

- a) **Maximum Force:** The magnetic force will be maximum, when the angle between the magnetic field and current is 90° .

$$(1) \Rightarrow F_M = BIL \sin(90^\circ) \quad (\because \sin 90^\circ = 1) \\ \Rightarrow F_M = BIL$$

- b) **Minimum Force:** The magnetic force will be minimum (i.e. zero), when the angle between magnetic field and current is 0° .

$$(1) \Rightarrow F_M = BIL \sin(0^\circ) \quad (\because \sin 0^\circ = 0) \\ \Rightarrow F_M = 0$$



5. Why does a compass needle point north?

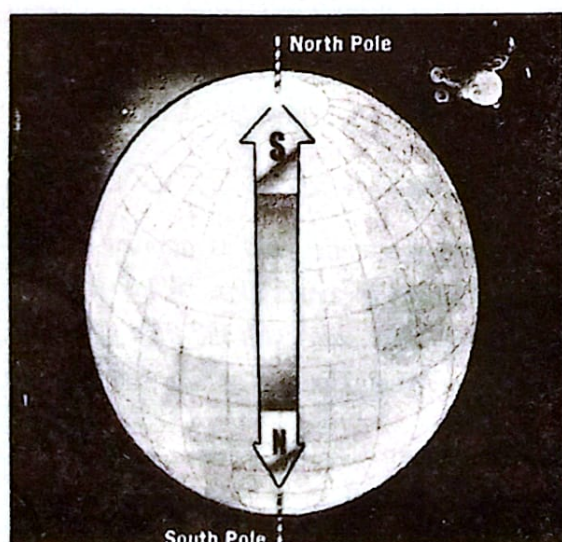
Ans. As we know that the earth acts like a bar magnet. The magnetic field of earth is caused by the currents at its core. The south pole of earth's magnetic field is located near the earth's geographical north.

The compass needle is itself a tiny magnet. Thus, the compass needle interacts with the earth's magnetic field and align its north pole with the earth's magnetic south which is located near the earth's geographical north.



CONCEPT

(Optional)



6. How can a magnetic field be used to generate electric current?

Ans. The magnetic field can be used to generate electric current by using the effect of electromagnetic induction. The electric current can be produced by:

- Moving a bar magnet inside a coil.
- Moving a coil in a magnetic field.
- Placing a coil in a varying magnetic field.

In each of the above cases, the varying magnetic field pushes the electrons in the wire and produces an electric current in the wire.



7. What would happen if we use a slip ring to drive a DC motor?

Ans. DC motors use split rings (or commutators) in order to reverse the direction of current through the coil after every half rotation. This is one of the key features of DC motor which keeps the torque in one direction and the coil rotates continuously.

If we use slip ring instead of split ring, then the rotation of the coil will not be possible. Because slip ring will not be able to reverse the direction of current through the coil.



8. The primary coil of a transformer is connected to a DC battery. Is there an emf induced in the secondary coil? why?

Ans. Transformers work on the principle of mutual induction, i.e. when the current in the primary coil changes, the induced magnetic field linking the secondary coil also changes and the phenomenon of electromagnetic induction occurs in the secondary coil. Now, if we connect the primary coil of a transformer to a DC battery, there will no change in the magnitude and direction of the current and a constant magnetic field will be produced. As a result, no emf will be induced in the secondary coil.

Numerical Questions

1. A 1.5 m long wire carries a current of 5 A, at right angle to a uniform magnetic field of 0.04 T. Determine the force exerted on the wire.

Given data :

Length 'L' = 1.5 m

Current 'I' = 5 A

Magnetic field strength 'B' = 0.04 T

Angle ' θ ' = Right angle (90°)

Required :

Magnetic force ' F ' = ?

Solution :

As we know that

$$F_B = ILB \sin \theta$$

(Put the values)

$$F_B = 5 \times 1.5 \times 0.04 \times \sin 90^\circ$$

($\because \sin 90^\circ = 1$)

$$F_B = 0.3 \text{ T}$$

2. A wire carrying a direct current of 10.0 A is suspended 5.0 m east between a house and a garage perpendicular to the Earth's magnetic field of 5.0×10^{-5} T. what is the magnitude of the force that acts on the conductor?

Given data :

Current 'I' = 10.0 A

Length 'L' = 5.0 m

Magnetic field strength 'B' = 5.0×10^{-5} T

Angle ' θ ' = Right angle (90°)

Required :

Magnetic force ' F_B ' = ?

Solution :

As we know that

$$F_B = ILB \sin 90^\circ$$

(Put the values)

$$F_B = 10 \times 5 \times 5 \times 10^{-5} \times \sin 90^\circ$$

($\because \sin 90^\circ = 1$)

$$F_B = 2.5 \times 10^{-3} \text{ A}$$



3. A 10 cm wire at 30° to uniform magnetic field of 0.06 T is exerted by a force of 0.024 N. What is the current flowing through the wire?

Given data :

Length 'L' = 10 cm = 10×10^{-2} cm

Magnetic force ' F ' = 0.024 N

= 2.4×10^{-2} N

Magnetic field strength 'B' = 0.06 T

= 6×10^{-2} T

Angle ' θ ' = 30°

Required :

Current 'I' = ?

Solution :

As we know that

$$F_B = ILB \sin \theta$$

$$\Rightarrow I = \frac{F_B}{LB \sin \theta}$$

(Put the values)

$$I = \frac{2.4 \times 10^{-2}}{10 \times 10^{-2} \times 6 \times 10^{-2} \times \sin 30^\circ}$$

$$I = \frac{2.4 \times 10^{-2}}{60 \times 10^{-4} \times 0.5} = \frac{2.4 \times 10^{-2}}{30 \times 10^{-4}}$$

$$I = 0.08 \times 10^2 \text{ A}$$

$$I = 8 \text{ A}$$



4. If the current through the primary coil changes from -5 A to +5 A in 0.05 s, such

that the induced emf is 2.8 V. what is the mutual inductance?

Given data :

Change in current through

primary coil ' ΔI_p ' = 5 - (-5) = 10 A

Induced emf ' ε_s ' = 2.8 V

Time ' Δt ' = 0.05 s

Required :

Mutual inductance ' M ' = ?

Solution :

As we know that

$$M = \frac{\varepsilon_s}{\Delta I_p / \Delta t} \quad (\text{Put the values})$$

$$M = \frac{2.8}{10/0.05} = \frac{2.8}{200}$$

$$M = 0.014 \text{ H}$$

or $M = 14 \text{ mH}$

5. A transformer connected to a 120 V AC line is to supply 9600 V for a neon sign. (a) what is the ratio of secondary to primary turns of the transformer? (b) if the transformer consisted of 275 primary windings, how many secondary windings would there be?

Given data :

Input voltage ' V_p ' = 120 V

Output voltage ' V_s ' = 9600 V

Primary coil turns ' N_p ' = 275

Required :

a) Turns ratio ' N_s/N_p ' = ?

b) Secondary coil turns ' N_s ' = ?

Solution :

a) As we know that

$$\frac{N_s}{N_p} = \frac{V_s}{V_p} \quad (\text{Put the values})$$

$$\frac{N_s}{N_p} = \frac{9600}{120}$$

$$\frac{N_s}{N_p} = 80$$

b) As

$$\frac{N_s}{N_p} = \frac{V_s}{V_p}$$

$$\Rightarrow N_s = \left(\frac{V_s}{V_p} \right) N_p \quad (\text{Put the values})$$

$$N_s = \frac{9600}{120} \times 275$$

$$N_s = 2200$$

6. How many turns would you want in the secondary coil of a transformer having 400 turns in the primary, if it were to reduce the voltage from 220 V AC to 3.0 V AC?

Given data :

Primary turns ' N_p ' = 400

Input (primary) voltage ' V_p ' = 220 V

Output (secondary) voltage ' V_s ' = 3.0 V

Required :

Secondary turns ' N_s ' = ?

Solution :

a) As we know that

$$\frac{N_s}{N_p} = \frac{V_s}{V_p}$$

$$\Rightarrow N_s = \frac{V_s}{V_p} N_p \quad (\text{Put the values})$$

$$N_s = \frac{3.0}{220} \times 400$$

$$N_s = \frac{3.0}{22} \times 40$$

$$N_s = 5.45$$

7. A transformer steps down a main supply of 220 V AC to operate a 12 V AC lamp. Calculate the turns ratio of the windings.

Given data :

Input volage ' V_p ' = 120V

Output voltage ' V_s ' = 12V

Required :

Turns ratio ' N_s/N_p ' = ?

Solution :

As we know that

$$\frac{N_s}{N_p} = \frac{V_s}{V_p} \quad (\text{Put the values})$$

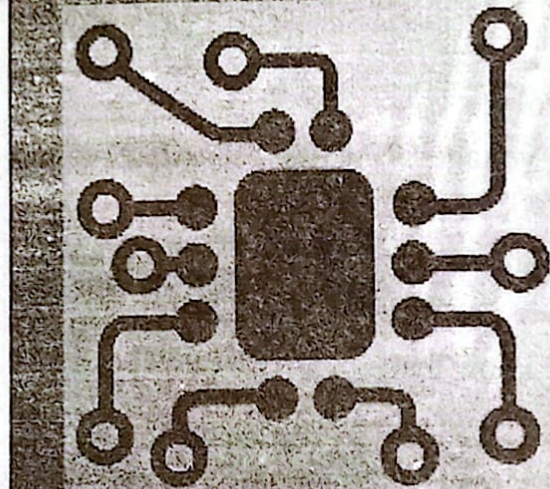
$$\frac{N_s}{N_p} = \frac{12}{220}$$

$$\frac{N_s}{N_p} = 0.05$$



Heinrich Rudolf Hertz (22 February 1857 - 1 January 1894) is considered by some people to be the father of electromagnetism.

He was a German physicist who first conclusively proved the existence of the electromagnetic waves predicted by James Clerk Maxwell's equations of electromagnetism. When Heinrich Rudolf Hertz was born, the world knew that electromagnetism existed (see James Clerk Maxwell, Joseph Henry, Michael Faraday, and others). But the world didn't know it for sure. Hertz did not invent the physical interaction that occurs between electrically charged particles of course. He was just the first to prove that it was definitely real.



UNIT 16

INTRODUCTORY ELECTRONICS

Electronics

Electronics is the branch of physics and technology which deals with the development of devices and systems that involve the flow of electrons in vacuum and matter.

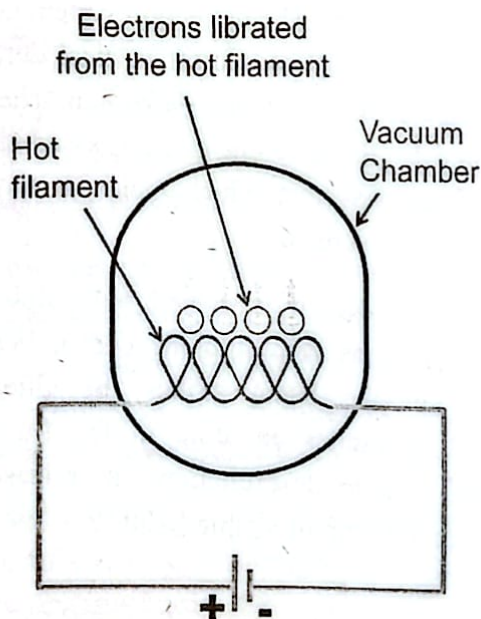
Thermionic Emission

The process by which free electrons are emitted from the surface of a metal when external heat energy is supplied is called thermionic emission.

Metals under normal temperature: As we know that metals contain large number of free electrons. These free electrons have some kinetic energy, however, this kinetic energy is not sufficient to overcome the attractive force between the free electrons and the atomic nuclei. Hence, free electrons cannot escape from metal surface under normal temperature.

Work function: The minimum external energy required by an electron to escape from the metal surface is called work function.

Metals under high temperature: When a metal is heated, the free electrons gain energy. If the energy gained by the electrons is sufficient to overcome the work function, they escape from the metal. These escaped electrons are called thermions.



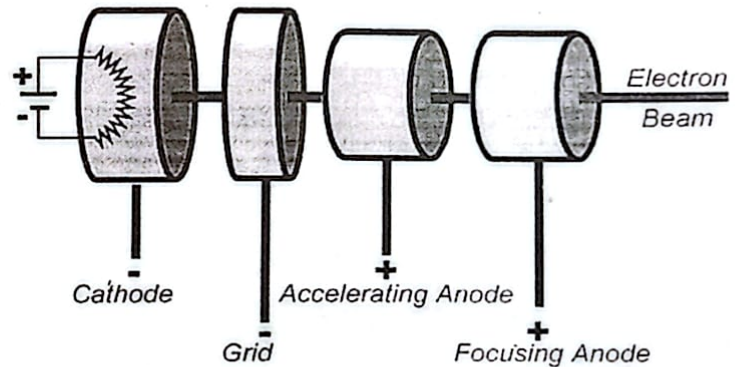
As shown in the figure, thermionic emission can be achieved by passing electric current through a tungsten filament.

Electron Gun

An electron gun is a device that produces a focused and accelerated electron beam.

Applications: Electron gun is a versatile electric component of many devices such as TV, electron microscope, CRO, etc.

Construction: An electron gun consists of a very low pressure tube, with a negatively charged electrode (i.e. cathode) and a positively charged electrode (i.e. anode), as shown in the figure.



Working: The electrons are emitted by the cathode which is heated up by a tungsten filament. For this purpose, a voltage of $\sim 6V$ is applied to the filament and a current of $\sim 600mA$ passes through it. To achieve high thermionic emission, the ends of the cathode is coated with a layer of barium and strontium oxide.

The emitted electrons are attracted and accelerated by accelerating anode which is kept at high positive potential. Finally, the electrons are focused by focusing anode to get an accelerated and focused electron beam.

Between the cathode and accelerating anode, there exists a control grid which controls the number of electrons in the electron beam. For this purpose, the control grid is kept at negative potential. When

the negative potential of the control grid is increased, then the lower energy electrons will be repelled back and will not be able to cross it. Thus, by increasing the negative potential, we can decrease the number of electrons in the beam and vice-versa.



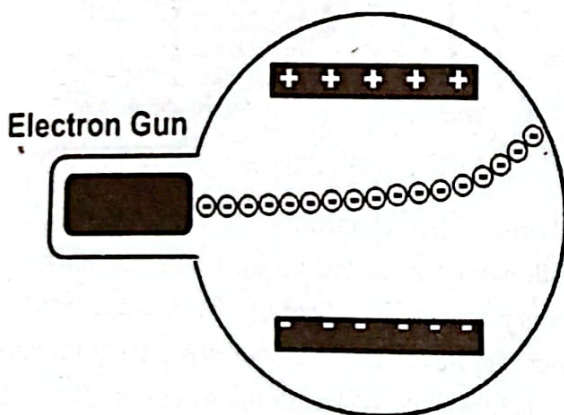
Cathode Rays

The beam of electrons is called cathode ray because it is emitted by the cathode.

Since cathode rays consist of fast-moving electrons that possess negative charge, therefore, cathode rays are affected by electric and magnetic fields.

Deflection by electric field

As the cathode ray consists of electrons, therefore, it is attracted by the positively charged plate and repelled by the negatively charged plate.

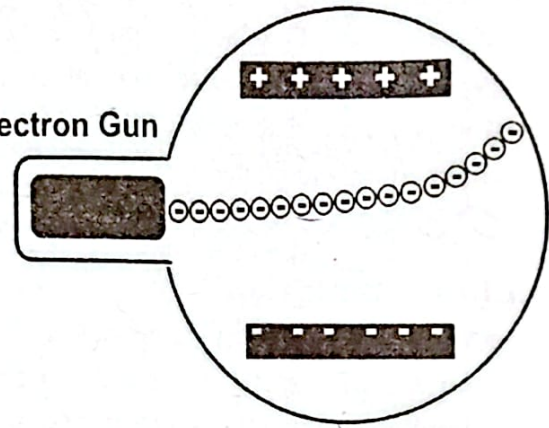


Deflection by Electric Field

Deflection by magnetic field

As we know that a moving charge is acted upon by a force when it passes through a magnetic field. Since cathode ray consists of fast-moving electrons, therefore, a magnetic force will act on it when it pass through a magnetic field. The direction of the force can be determined by right hand rule (III) or Fleming left hand rule for current.

Electron Gun



Deflection by Electric Field

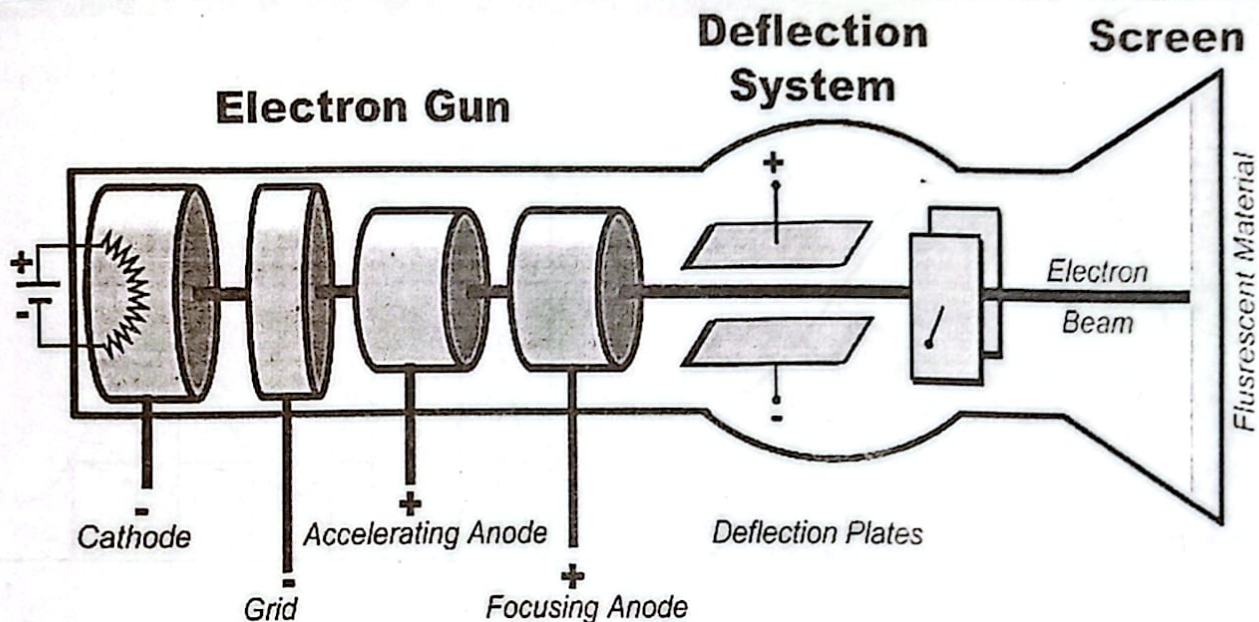
Cathode Ray Tube (C.R.T)

Cathode ray tube is a vacuum tube in which electron beam is allowed to strike a fluorescent screen to produce images. It consists of a highly evacuated tube that encloses the following main three parts.

Electron Gun: The electron gun consists of a cathode, control grid, accelerating anode, and focusing anode. The electrons are emitted from cathode when it is heated by a tungsten filament. In order to make an accelerated and focused electron beam, these electrons are first accelerated by accelerating anode and then focused by the focusing anode.

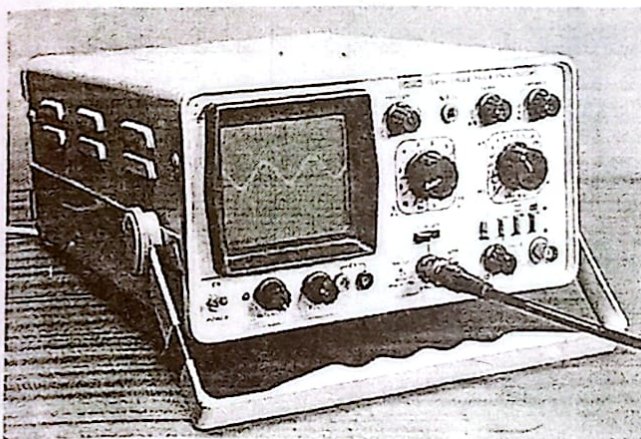
Deflection System: The deflection system consists of two pairs of plates: one for vertical deflection and the other for horizontal deflection. The beam generated by the electron gun is passed through the deflection system which makes it to sweep over the entire screen.

Screen: The screen is coated with fluorescent material such as zinc sulphide (ZnS). When an electron in the beam strikes the fluorescent material, it excites an atom in the fluorescent material. Upon de-excitation, it releases the energy in the form of visible light.



Cathode Ray Oscilloscope (C.R.O)

Cathode ray oscilloscope is an electronic test instrument which encloses a C.R.T. as its main part.



A C.R.O. is used to:

- Display different types of waveforms.
- Measure short time interval.
- Measure potential difference (voltage).

The oscilloscope is often used to troubleshoot a malfunctioned electronic equipment because it can show the signal graphically. The graph of the signal displayed by oscilloscope shows much more details as compared to a voltmeter.

The oscilloscope is also used to check newly designed circuitry for design errors, bad voltage levels, electrical noise, etc.

Introduction to Electronics

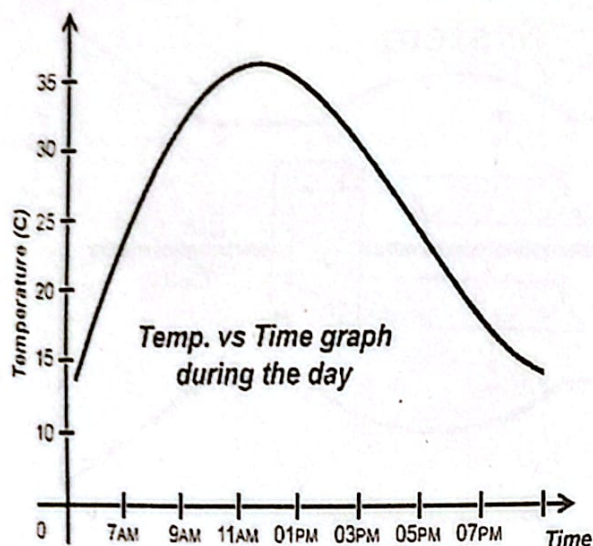
Electronics is the branch of physics and technology that deals with the design of circuits using transistors and microchips and deals with the behavior and movement of electrons in vacuum and matter (i.e. semiconductor, conductor and gas).

Electronics has many applications in Information and Communication Technology (I.C.T.).

Analogue and Digital Electronics:

Analogue Quantities: The quantity that has continuous values is called analogue quantity. The continuous values of an analogue signal mean its infinite number of possibilities. All natural process and phenomena in the real world are analogue.

For example, consider the rise in temperature during the day. The temperature rises in a continuous manner. For example, no one can say that it was 0°C just a moment before and now it is 10°C . The temperature varies by passing through infinite values (i.e. rational and irrational numbers) between two points.



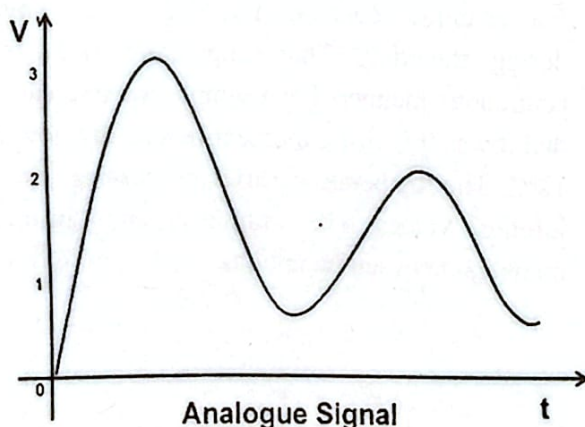
It means that when an analogue quantity changes, it passes through a series of infinite steps of approximately zero size.

Digital Quantities: The quantity that has discontinuous (or discrete) values is called digital quantity. Digital quantities are processed and stored in digital systems which has only two discrete states i.e. ON and OFF, represented by binary numbers 1 and 0, respectively.

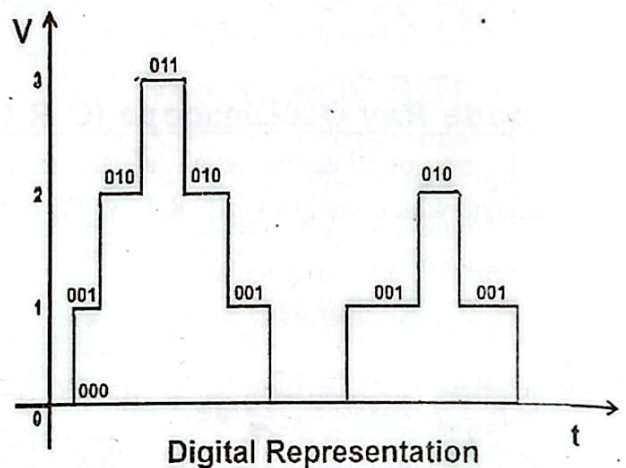
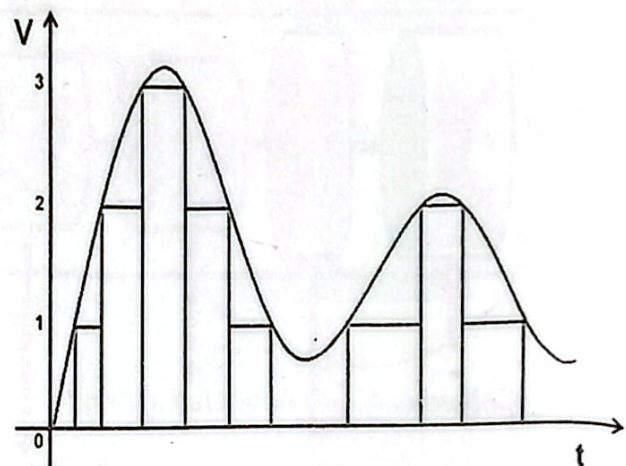
Interconversion of Analogue and Digital Signals:

If we want to process and store analogue information by an electronic machine, we have to convert them into digital format. For this purpose, a circuit called Analogue to Digital Converter (ADC) is used.

Consider the example of digital recording of an audio signal shown in the following figure.



The ADC converts the analogue signal to a series of 1s and 0s, as shown in the figure.



As shown in the above figure, the ADC gathers several samples of the analogue signal instead of the continuous infinite values.

Now if we want to play the recorded audio signal, a circuit called Digital to Analogue Converter (DAC) converts the digital string (series of 1s and 0s) back to analogue signal, because a speaker requires analogue signal to produce sound.

Advantage of digital recording: Digital recording eliminates the imperfections in an audio signal such as electrostatic noise and magnetic tap hiss. In analogue signals, these imperfections are easily picked up by human ears while in digital representation these slight variations do not change an ON level to an OFF level.



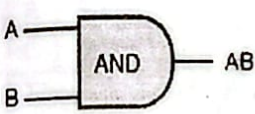
Logic Gates

Logic gates are the basic building blocks of digital electronics. A logic gate has one or more input terminals and only one output terminal. The output may be HIGH (1) or LOW (0) depending on the digital levels (0 and 1) at the input terminals.

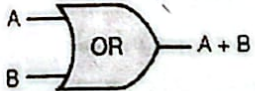
The operation of a logic gate is represented in table, called truth table, that contain all the possible input combinations and their corresponding outputs.

The five basic logic gates are:

1. **AND Gate:** The AND gate will give HIGH (1) output only when all the inputs are HIGH. While the output will be LOW (0) when all the inputs or any one input is LOW (0).

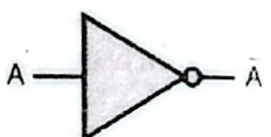
Symbol of AND Gate	Truth Table of AND Gate		
	Inputs		Output
	0	0	0
	0	1	0
	1	0	0
	1	1	1

2. **OR Gate:** The OR gate will give LOW (0) output only when all the inputs are LOW (0). While the output will be HIGH (1) when all the inputs or any one input is HIGH (1).

Symbol of OR Gate	Truth Table of OR Gate		
	Inputs		Output
	0	0	0
	0	1	1
	1	0	1
	1	1	1

3. **NOT Gate (or Inverter):** Not gate has only one input and one output. It is used to complement or invert a digital signal. It will

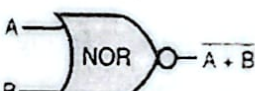
give LOW input when the input is HIGH and vice-versa.

Symbol of NOT Gate	Truth Table of NOT Gate	
	Input	Output
	0	1
	1	0

4. **NAND Gate:** A NAND gate is a NOT-AND gate which operates as the AND gate with an inverter at its output. A NAND gate will give only LOW (0) output only when all the inputs are HIGH. While the output will be HIGH when all the inputs or any one input is LOW (0).

Symbol of NAND Gate	Truth Table of NAND Gate		
	Inputs		Output
	0	0	1
	0	1	1
	1	0	1
	1	1	0

5. **NOR Gate:** A NOR gate is a NOT-OR gate which operates as the OR gate with an inverter at its output. A NOR gate will give HIGH (1) only when all the inputs are LOW (0). While the output will be LOW (0) when all the inputs or any one input is HIGH (1).

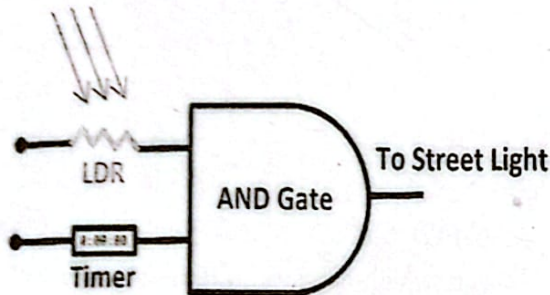
Symbol of NOR Gate	Truth Table of NOR Gate		
	Inputs		Output
	0	0	1
	0	1	0
	1	0	0
	1	1	0

Uses of Logic Gates

Automatic light bulb switching:

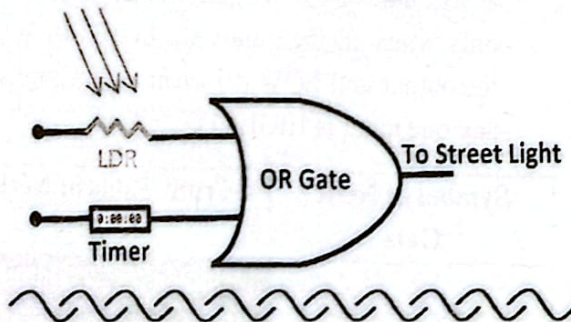
Both AND and OR gates can be used to automatically switch the streetlights on and off.

For example, if it is desired to switch on or off the streetlights after appropriate time and light level, then AND gate is used, as shown in the figure.



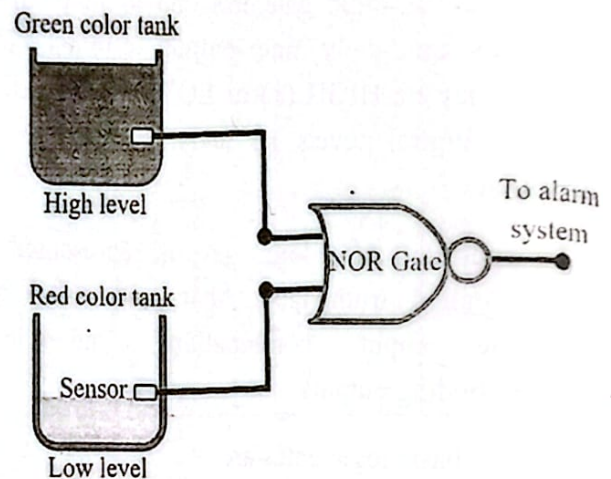
During the day the light shines on LDR (Light Dependent Resistor), the resistance is high enough to prevent current to enter the input terminal. So, the input of the gate is LOW (0). While, in the evening when light fades out, the resistance of LDR decreases and the current passing through it enters the input terminal and it turns to HIGH (1). Now if the timer time is reached, the other input will also turn to HIGH (1) and the streetlight will be switched on. But if the timer time is not reached, the other input will remain LOW (0) and the streetlight will remain switched off.

But if we want to switch on the streetlight when either light is low or timer time is reached, we can use an OR gate, as shown in the figure.



Textile Coloring Plant: The textile coloring plant shown in the figure has two tanks to store red color and green color. Each tank has a sensor which produces a high level of 5V when the tank

is more than one-quarter full and produces a low level of 0V when the tank drops to one-quarter full or less.



The circuitry consists of a NOR gate whose input terminals are connected to the sensors. When both the tanks or one of the tanks is above one-quarter full, the output of the NOR gate will be LOW (0). But, as soon as both the tanks are below one-quarter full, the sensors' outputs will be low and NOR gate will give HIGH (1) output and alarm is raised.



Michael Faraday (September 22, 1791 - August 25 1867) was an English scientist is considered as the father of electromagnetism. He contributed to the study of electromagnetism and electrochemistry. His main discoveries include the principles underlying electromagnetic induction, diamagnetism, and electrolysis.

EXERCISE

Multiple Choice Questions

1	Cathode rays are beam of:			
	A	Protons	B	Electrons
	C	Ions	D	Neutrons
2	If electric field is applied parallel to the direction of electron beam, the electrons will:			
	A	Speed up	B	Slow down
	C	Deflect	D	Not change its state
3	If magnetic field is applied parallel to the direction of electron beam, the electrons will:			
	A	Speed up	B	Slow down
	C	Deflect	D	Not change its state
4	The electronic circuit that gives high [1] output when all its inputs are high [1] is called ____ gate.			
	A	AND	B	OR
	C	NAND	D	NOR
5	The electronic circuit that gives high [1] output when one or more of its inputs are high [1] is called ____ gate.			
	A	AND	B	OR
	C	NAND	D	NOR
6	The electronic circuit that gives low [0] output when all its inputs are high [1] is called ____ gate.			
	A	AND	B	OR
	C	NAND	D	NOR
7	The electronic circuit that gives low [0] output when one or more of its inputs are high [1] is called ____ gate.			
	A	AND	B	OR
	C	NAND	D	NOR
8	The Boolean equation for OR gate is:			
	A	$X = AB$	B	$X = A + B$
	C	$X = \overline{AB}$	D	$X = \overline{A + B}$
9	The Boolean equation for NAND gate is			
	A	$X = AB$	B	$X = A + B$
	C	$X = \overline{AB}$	D	$X = \overline{A + B}$

Conceptual Questions

1. What are free electrons?

Ans. The electrons that are not bound to a particular atom and free to move randomly through the metal are called free electrons. As these electrons are free to move everywhere within the metal, they are still bound to the metal and an external energy such as thermal energy is required to escape them from the metal. The minimum energy required to eject a free electron from the metal is called *work function* of the metal.

2. What is the function of an accelerating anode in an electron gun?

Ans. The accelerating anode has a cylindrical shape and is placed next to the control grid. A high positive potential is applied to it. When the electrons leave the control grid, they are attracted by accelerating anode. As a result, the electrons accelerate, thus providing high energy to electron beam.

3. If the electron beam in a television tube is striking just one point on the screen at a time, how can we get a full picture? Explain.

Ans. Since the electron beam can strike just one point on the screen at a time, but it is moved back and forth across the screen in a specified pattern called raster scan. In this way, the electron beam writes lines, one after another until it has filled the screen. It then comes back very quickly to its initial position and repeats the process.

4. Why image is distorted when a magnet is brought close to old television screens or monitors with cathode ray tube (CRT) inside?

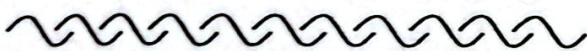
Ans. As we know that an electron beam consists of fast-moving electrons and a magnetic field greatly affect the motion of moving charges. When a magnet is brought close to an old television screens or monitors with CRT inside, the magnetic field of the magnet deflects the electron beam away from where it should strike the fluorescent screen. As a result, distorted image is formed on the screen.



5. Assuming that cathode rays are beam of charged particles, how could you demonstrate that these particles are negatively charged? Explain.

Ans. Cathode rays are negatively charged particles (i.e. electrons) and we can easily demonstrate this evidence if we pass these rays through an electric field or magnetic field.

If we pass cathode rays through an electric field, they are attracted by the positive electrode. This confirms that they are negatively charged particles. Now if we pass these rays through a magnetic field, they deflect in such a way that shows their negative nature according to Fleming left hand rule.



6. If there are 4 inputs in any logic gate, how many combinations are possible?

Ans. The number of possible input states in any logic gate is given by

$$\text{Number of possible input states} = 2^n \dots\dots(1)$$

Where, n is the number of inputs.

In the present case, $n = 4$

$$\begin{aligned} (1) \Rightarrow \text{Number of possible input states} &= 2^4 \\ &= 2 \times 2 \times 2 \times 2 \\ &= 16 \end{aligned}$$



7. What conditions produce a high (1) output from an AND gate and NOT gate?

Ans. The truth table of an AND gate shows that both the inputs must be high (1) to give a high (1) output.

Inputs		Output
A	B	$X = AB$
0	0	0
0	1	0
1	0	0
1	1	1

The truth table of a NOR gate shows that both the inputs must be low (0) to give a high (1) output.

Inputs		Output
A	B	$X = A + B$
0	0	1
0	1	0
1	0	0
1	1	0



8. What are the algebraic Boolean expressions to represent the output of AND, OR, NOT, NAND and NOR gates?

Ans. Boolean expression for AND gate:

$$X = AB \text{ (read as } X \text{ equals } A \text{ and } B)$$

Boolean expression for OR gate:

$$X = A + B \text{ (read as } X \text{ equals } A \text{ or } B)$$

Boolean expression for NOT gate:

$$X = \bar{A} \text{ (read as } X \text{ equals NOT } A)$$

Boolean expression for NAND gate:

$$X = \overline{AB} \text{ (read as } X \text{ equals NOT } A \text{ and } B)$$

Boolean expression for NOR gate:

$$X = \overline{A + B} \text{ (read as } X \text{ equals NOT } A \text{ or } B)$$





UNIT 17

INFORMATION & COMMUNICATION TECHNOLOGY

Information and Communication Technology

The infrastructure and components that enable modern computing to create, access, analyze and communicate information is called ICT (Information & Communication Technology).

Components of ICT

- A. Data and Information:** Data are simply bits of information. It means that data are meaningless until they are processed, interpreted, organized or presented. But when data are processed, interpreted, organized or presented so as to make them meaningful or useful, then they are called information.
- B. Hardware:** Hardware are the physical parts or machinery that we can touch, e.g. mouse, keyboard, printer, etc.
- C. Software:** Software means the operating system and applications. These are machine-readable instructions that direct the hardware to store, process, transmit, receive and retrieve information in a specific manner.
- D. Procedures:** These are set of instructions and rules to design and use information system that can be changed from time to time. It means that the information system must be flexible to incorporate these.
- E. Human Resource:** Human resource consists of the people who design and operate the software, and build the hardware.



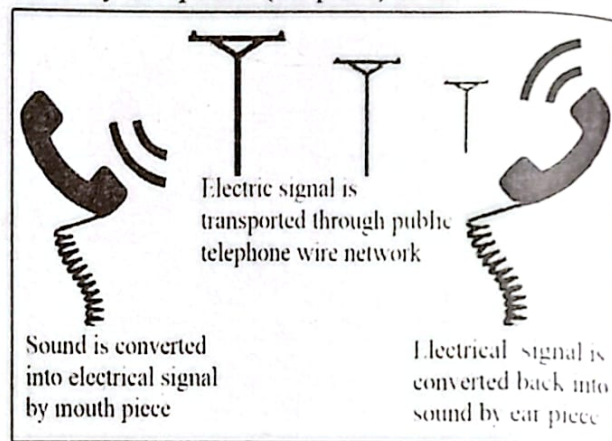
Flow of Information

Flow of information means the movement of information between people and systems. It focuses on the paths and means through which signals (electric or electromagnetic representations of data or information) are transmitted. The following are the three paths and means of information flow.

Transmission of information as electrical signals through wires: In this technique the information is converted to electrical signals and

sent through wires (twisted pair, coaxial cable, etc.). The information is converted back to original form at the receiver end.

For example, a simple telephone model the voice is converted into electrical signals by the microphone (mouth piece) and converted back to sound by the speaker (ear piece) at the receiver.

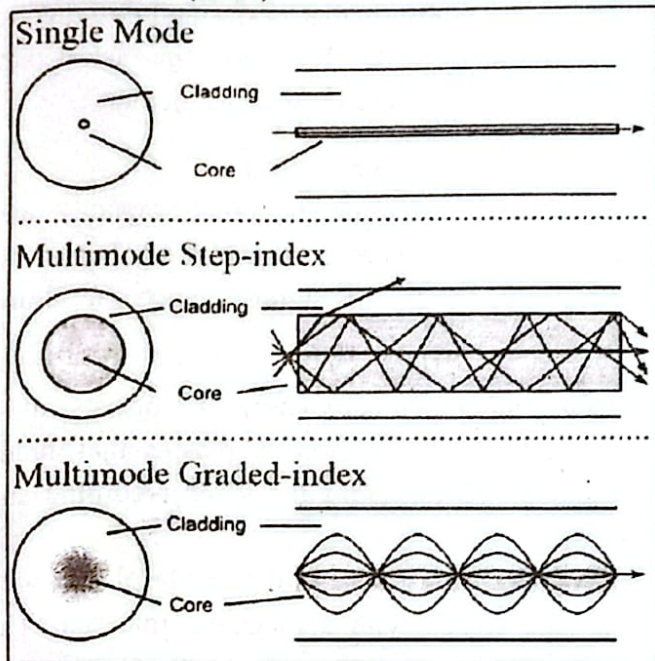


Both analog and digital signals can be transmitted through this technique. For analog signals, amplifiers are required at some distances, while for digital signals, repeaters are required at some distances depending upon the type of wire used.

Transmission of information as electromagnetic signals through optical fibers: In this technique the information is converted into voltage signals that are used to produce light either by *light emitting diode* (LED) or *injection laser diode* (ILD). The following are the modes of optical fiber transmission.

- a. Step-index multimode:** In this mode the rays at low angles are totally internally reflected and travel along the fiber, while the other rays are absorbed by the cladding. This form of propagation is best suited for transmission over very short distances.
- b. Single mode:** In this mode the core is reduced to the order of a wavelength. Due to which only a single angle or mode can pass. This form of propagation is typically used for long distance applications such as telephone and cable television.
- c. Graded-index multimode:** In this mode the core refractive is higher at the center and

decreases gradually towards the cladding. Due to the variation in the refractive index, the light in the core curves helically. This form of propagation is often used in local area networks (LAN).



Transmission of information as radio-waves through air or space: In this technique the radio-frequency electrical signals representing information is converted into electromagnetic energy by the transmission antenna and radiated into the surrounding environment. At the receiving end, the electromagnetic energy falls on the reception antenna and converted back to radio-frequency electrical energy.

In two-communication, the same antenna is used for both transmission and reception.

Telecommunication Devices

The devices used to carry information from one place to another place are called telecommunication devices.

Fax Machine: A fax machine is used to send as well as receive black and white documents electronically over a telephone network. It has a built-in scanner and a printer. It scans the document line by line and

converts it to electrical pulses that are transmitted through the telephone wire network. At the receiver end, another fax machine receives the electrical pulses and use them to control a printer.

Cell Phone: Cell is the area around a tower in which a signal can be received. That is why mobile phone are also called cell phones. These are wireless phones that receive their signals in the cell. Each cell phone has both a transmitter and receiver for two-way communication. In addition to attend voice calls, a cell phone can perform other functions such as,

- i. Storing contact information
- ii. Making task or to-do lists
- iii. Keep track of appointments and set reminders
- iv. Send and receive text messages.
- v. Use the built-in calculator for simple math
- vi. Get information (news, entertainment, stock quotes, etc.) from the internet
- vii. Send or receive e-mail.

Photo phone: The photo phone was invented by Alexander Graham Bell in 1980. A photo phone transmits sound using light. The voice is projected by an instrument towards a mirror. The mirror starts vibration similar to the vibration in the voice. The vibration of the mirror is captured by the sunlight falling on it and projected to the photophone receiver. There they are converted back to sound.

Computer: A computer is a device that can perform sequences of arithmetic or logic operation automatically via computer programming. A computer can follow generalized sets of operations, called programs, which enable it to perform an extremely wide range of tasks. A computer can be as big as a whole room and small enough to fit in a pocket. e.g.

Mainframe computers are extremely large computers used in organizations where very large amounts of data are processed.

Desktop or Personal Computer is a general purpose computer made up of separate components such as monitor, keyboard, mouse, processor and storage.

Laptop or notebook are portable computers that have all the components are together in a single unit.

Internet and Email

Internet: The internet is worldwide system of computer networks that facilitate worldwide communication and access to data resources.

Email: Electronic mail (email) is a method of exchanging messages (mails) between people using electronic devices.

Uses of internet

1	Communication	- Email - Social media (facebook, twitter, instagram, etc.) - Read or write blogs - Chat-room - Forums - Internet telephone (VOIP)
2	Exploring the world	- Exploring earth through google earth - Almanacs and encyclopedias
3	Keeping up with events	- Reading newspapers and watching news channels - Listening radios and watching TV via live streaming
4	Managing life	- Online banking - Online shopping - Paying utility bills - Investing money - Keeping a calendar - Finding job
5	Study and research information	- Finding research papers and articles - Taking online classes
6	Entertainment	- Watching TV and movies - Watching online videos - Listen to music

Information Storage Devices

There are two main types of electronic data storage devices.

1. Primary storage devices:

They are generally smaller in size and designed to hold data temporarily. They have the fastest data access speed. e.g. RAM and cache memory.

2. Secondary storage devices:

They usually have large storage capacity and designed to store data permanently. e.g. hard disk, optical disk drive, USB storage device, etc. Some secondary storage devices are:

Audio and Video Cassettes: It consists of a rectangular casing made of plastic that holds magnetic tape for audio and video recording and replay.

A magnetic tape is made of flexible plastic with one side coated with a magnetic material. The information is stored in the form of magnetization pattern on the tape. An audio cassette can store music or sounds, while a video cassette can store both audio and video.

Hard disk: A hard disk drive (abbreviated as HDD) is a secondary storage device that stores data permanently. It consists of an air sealed casing that encloses one or more platters (disks) to which data is written using magnetic head.

Floppy: A floppy disk is a magnetic storage medium. It consists of a thin, flexible magnetic disk sealed in a square plastic casing. A floppy disk drive (abbreviated as FDD) is required for a computer to read and write data from a floppy disk.

CD and DVD: CD stands for Compact Disc, while DVD stands for Digital Versatile Disc. Both are used to read and write data in digital form. They are used to hold music, data or computer software. A DVD has a storage capacity of 4.7 GB which is about six times more than that of a CD. If we have a CD-R or DVD-RW installed in computer, we can store any data by burning a CD or DVD.

Flash Drive: A flash drive is a small, ultra-portable storage device. Unlike an optical drive or a traditional hard drive, it has no moving parts. It consists of a digital integrated circuit (IC) enclosed in a plastic or metal casing. Flash drives can be connected to computers and other digital devices via a built-in USB type-A plug.

Word Processing

Word Processing refers to the act of using a computer to create, edit, save, and print documents. For this purpose, a word processing software such as *WordPad*, *MS Word*, *Google Docs*, etc. Some of the functions of word processing software are:

- Creating, editing, saving, and printing documents
- Copying, pasting, moving, and deleting text within a document
- Formatting text, such as font type, bolding, underlining, or italicizing
- Creating and editing tables
- Inserting documents from other software
- Correcting spelling and grammar
- Performing repetitive tasks

Handling Information

Handling information means to use ICT for gathering, organizing, storing, retrieving, modifying, interpreting, and processing information. Following are the categories that are involved in handling information.

A. Data Management: Data management is the process of collecting, keeping, and using data securely, efficiently, and cost-effectively. The goal of data management is to help people and organizations use data within the bounds of policy and regulation.

B. Monitoring and Control: In ICT, monitoring means to monitor a project by comparing actual performance with the planned performance. While, controlling means to take

necessary actions to yield the desired outcomes. That is, whether the approved and authorized project is within the scope, on time and on budget so that the project proceeds with minimal risk.

EXERCISE

Multiple Choice Questions

1	The components of information and communication systems are humans, hardware, software, procedures and			
	A	Computers	B	Fields
		Data/information	D	Signals
2	Electric or electromagnetic representations of data or information is termed as			
	A	Computer		Signal
	C	Transmission	D	Software
3	The phenomenon of total internal reflection is used in transmission termed as			
	A	Electric wires		Optical fibers
	C	Electromagnetic waves	D	radio
4	Electrical conductor or system of conductors used either for radiating electromagnetic energy or for collecting electromagnetic energy is			
		Antenna	B	Satellite
	C	Repeater	D	Signal
5	Software that allows user to interact with computer system is			
	A	Hardware	B	Application
		Operating system	D	Program
6	Which of the following information storage device has no moving parts to store and retrieve information			
	A	CD/DVD	B	Hard drive
		Flash drive	D	Floppy
7	Which of the following information storage device is least used these days			
	A	CD/DVD	B	Hard drive
	C	Flash drive		Floppy
8	Telephone communication is the example of transmission of signals through			
	A	Wire	B	Optical fibers
	C	Electromagnetic waves		all

Conceptual Questions

1. Identify the most reliable means of storing information.

Ans. Strictly speaking, none of the existing information storing devices is reliable for long-term storage. However, some of the most reliable devices are compared in the following table.

Storage Device	Reliability
CD / DVD	Not very reliable. Can be easily scratched and the stored data can be corrupted.
Internal / External Hard disks	Fairly reliable. Can be damaged if dropped or exposed to extreme heat or strong magnetic fields.
Flash drives / SD cards	Usually very reliable. Limited number of recording and erasing cycles. Can be lost due to their small sizes.
Solid State Drive (SSD)	Very reliable. Cannot be affected by magnets or extreme temperatures.
Cloud	Very reliable. Minimizes any loss of data. Can be leaked. Not recommended for sensitive data.

2. How information is different from data?

Data	Information
1. Data is a collection of facts and figures.	1. Information is how we understand those facts in context.
2. Data is unorganized.	2. Information is structured or organized.
3. Data does not depend on information.	3. Information depends on data.
4. Data is measured in bits and bytes.	4. Information is measured in meaningful units like time, quantity, etc.
5. e.g. a student's test score.	5. e.g. average score of the class.

3. Why frequency band for uplink and downlink is different in transmission of microwaves through space?

Ans. In satellite communication, uplink is the link from a ground station up to a satellite and downlink is the link from a satellite down to ground station. The uplink frequency is kept

higher than the downlink frequency because of the following reasons.

- Plenty of power can be provided on earth for uplink transmission by using heavy generators, while satellites have power and weight limitations.
- Frequency is inversely proportional to the size of antenna. So large antennas can be installed on earth to receive the lower downlink frequency. While due to limited space, satellites use smaller antennas to receive the higher uplink frequency.

4. What does 'cell' in 'cell phone' refers to?

Ans. In wireless technology, a cell is the geographical area covered by a cellular telephone transmitter (tower). That is why a mobile phone is often called cell phone. Depending on the transmission power, location and technology deployed, the cell provided by a transmitter (cell site) can range from a few kilometers to thousands of kilometers in diameter.

5. Can internet be used for shopping? Give an example.

Ans. Yes, internet can be used for shopping. This form of shopping is called online shopping or e-shopping. For example, we can buy a wide variety of products from the comfort of our homes just by visiting the web site such as daraz.pk, mega.pk, amazon.com, aliexpress.com, etc.



6. How a flash drive is different from other storage devices?

Ans. Flash drive is different from other devices in many ways such as:

- It is more durable due to lack of moving parts.
- It provides a convenient way to transfer data between systems.
- It provides a convenient way to transport data due to its smaller size and weight.
- It is cheaper than other storage devices.
- Unlike CDs / DVDs, a computer does not require additional devices to read or store data in it.



Claude Elwood Shannon (April 30, 1916 - February 24, 2001) was an American mathematician, electrical engineer, and cryptographer known as "the father of information theory".

Information theory studies the quantification, storage, and communication of information.

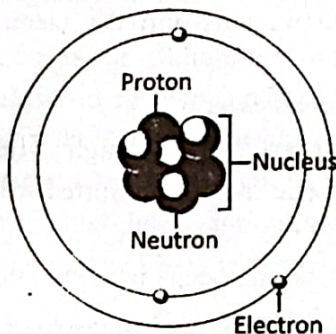


UNIT 18

NUCLEAR PHYSICS

Atomic Nucleus

Nucleus is the central dense part of an atom around which the electrons revolve in circular orbits.



Composition of Nucleus: A nucleus contains protons and neutrons. The combined name used for protons and neutrons is *nucleons*.

Charge on Nucleus: The proton has positive charge which is equal but opposite to that of electron (i.e. $+1.6 \times 10^{-19}C$). While the neutrons are neutral. Therefore, the charge on nucleus is positive due to the positive charge on protons.

Size of Nucleus: A typical atom has a diameter of about $10^{-10}m$, while the diameter of the nucleus is about $10^{-15}m$. It means that the nucleus is about 10^{-5} (or 1/100,000) of the size of atom.

Mass of atom: A nucleon (proton or neutron) is more than 1800 times massive than electron. The mass of electron is so small that it is neglected while taking the mass of atom. Therefore, the whole mass of an atom is equal to the mass of the nucleus.

Atomic Number (Z): The atomic number (sometimes called the charge number) is equal to the number of protons in the nucleus.

$$Z = P$$

Mass Number (A): The mass number is equal to the number of nucleons (protons and neutrons) in the nucleus.

$$A = P + N$$

Neutron Number (N): The neutron number is the number of neutrons in the nucleus and is given by

$$N = A - Z$$

Symbolic Representation of a nucleus:



Where X represents the chemical symbol for the element, Z represents the number of protons and A represents the number nucleons.

Nuclides: A nuclide (known as nuclear species) is a nucleus characterized by number of protons and number of neutrons.

All the atoms of a particular element contain the same number of protons but often contain different numbers of neutrons. The nuclei of atoms which have the same number of protons and neutrons are termed as nuclides.

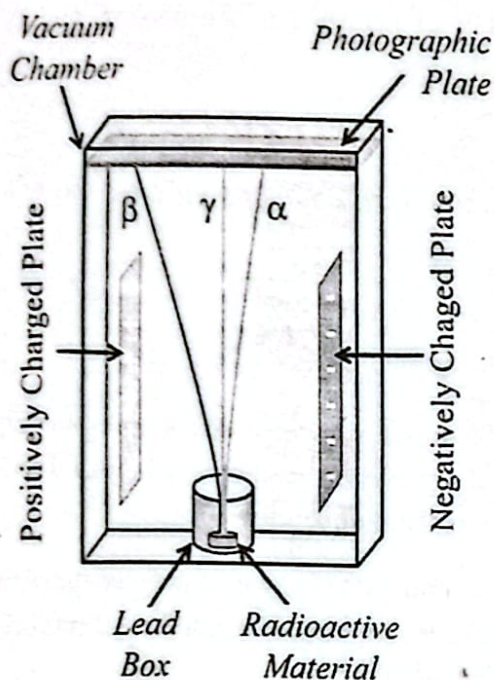
Radioactivity

The phenomenon of the spontaneous emission of subatomic particles or electromagnetic radiation by the unstable nuclei and disintegrate to form stable nuclei is called radioactivity.

A material that contain unstable nuclei are considered as radioactive material.

Explanation: In order to attain stability, the unstable nuclides emit three types of radiation: i) Alpha particles, which are ${}^4\text{He}$ nuclei; ii) Beta particles, which are either electrons or positrons; and iii) Gamma rays, which are high energy electromagnetic radiation. These radiations are distinguished by the following activity.

A lead box with a piece of radioactive element such as radium inside it is placed at the bottom of a vacuum chamber as shown in the figure.



A photographic plate is fixed at the top and an electric field is applied perpendicular to the beam. The image on the photographic plate shows three spots. It means that the radiation emitted by the radioactive element contain three beams that have different natures. The beam deflected toward the negative plate contains positively charged particles (i.e. alpha particle), the beam deflected toward the positive plate contains negatively charged particles (i.e. electrons) and the undeflected beam carries no charge (i.e. gamma rays).

Nature of emissions

i. *Alpha (α) emissions*

- Alpha particles are in fact helium nuclei (i.e. two protons and two neutrons bound together).
- Alpha emissions occur in very large atoms (i.e. atoms having high atomic numbers).
- It occurs when the neutrons to protons ratio in the nucleus is too low in order to restore balance.

ii. *Beta (β) emissions*

- Beta particles are electrons emitted from the nucleus.

- Beta emissions occur in nuclei that have to high neutrons to protons ratio.
- It occurs when an excess proton transforms into a proton and an electron. The proton stays in the nucleus and the electron is ejected.

iii. *Gamma emissions*

- Gamma rays are high energy electromagnetic radiation emitted from the nucleus.
- Gamma emissions occur when the nucleus has too much energy.



Alpha, Beta, and Gamma Radiation				
Particle	Symbol	Composition	Charge	Effect on parent nucleus
Alpha	α	2 protons and 2 neutrons	+2	Mass loss: new element produced
Beta	β	Electron	-2	No change in mass: new element produced
Gamma	γ	High energy electromagnetic radiation	0	Energy loss

Relative ionizing abilities

When radiation from a radioactive source interact with atoms, it can cause the atoms to lose electrons and thus become ionized.

The three types of radiation have different ionizing abilities in air. Alpha particles ionize air much strongly due to its large mass and charge than beta and gamma radiation. While gamma radiation has the least ionizing ability as compared to alpha and beta radiation.

Relative penetrating abilities

During the ionization process, the radiation loses energy. Therefore, the greater the ionizing power of a radiation, the smaller will be its penetrating ability.

Alpha particles, having the greatest ionizing ability, can barely penetrate a sheet of paper and has a range of a few centimeters in air. Beta particles, having smaller ionizing ability than alpha particles, can penetrate a few centimeters of aluminum and has a range of about 1m in air. Gamma rays, having the smallest ionizing ability, can penetrate several centimeters of lead and has an infinite range in air.

Nuclear Transmutation

The process through which atoms of one chemical element or isotope converts into atoms of another element is called nuclear transmutation.

Nuclear transmutation occurs naturally in radioactive materials. In this case, it is termed as nuclear decay, in which an unstable nucleus (parent nucleus) transforms into a relatively more stable nuclide (daughter nucleus).

Alpha decay: The mathematical relation for the alpha decay is

$${}_Z^AX = {}_{Z-2}^{A-4}Y + \alpha + Q \dots \dots \dots (1)$$

Equation (1) shows that the newly formed nuclide (Y) has a mass number reduced by four and atomic number reduced by two.

For example, ${}_{104}^{261}\text{Sg} \rightarrow {}_{102}^{259}\text{Rf} + {}_2^4\text{He} + Q$

Beta decay: The mathematical relation for the beta decay is

$${}_Z^AX = {}_{Z+1}^AY + \beta + Q \dots \dots \dots (2)$$

Equation (2) shows that beta decay does not change the number of nucleons (mass number) but changes a neutron into a proton. As a result, the newly formed nuclide (Y) has same mass number as that of the parent nuclide and atomic number increased by one.

For example, ${}_{6}^{14}\text{C} \rightarrow {}_{7}^{14}\text{N} + \beta + Q$

Gamma decay: The mathematical relation for gamma decay is

$${}_Z^AX^* = {}_Z^AX + \gamma \dots \dots \dots (3)$$

Equation (3) shows that the nucleus changes from a higher energy state to a lower energy state by the emission of electromagnetic radiation.



Unit of Radioactivity

The SI unit of activity is the becquerel 'Bq' which is defined as *one decay per second*. But a common unit of activity is the curie 'Ci' which is defined as *the activity of one gram of radium*. One curie is equal to 3.70×10^{10} decays per second.

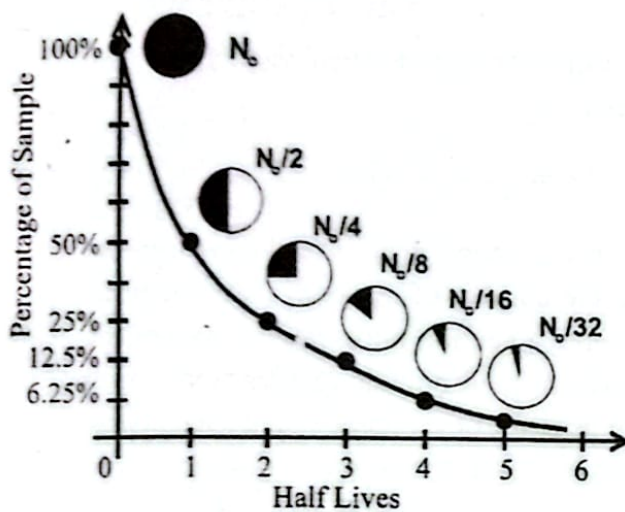
$$1\text{Ci} = 3.70 \times 10^{10}\text{Bq} \\ = 3.70 \times 10^{10}\text{decays/second}$$



Half Life

The time duration in which half of the radioactive nuclei in a sample decay is called half-life.

The decrease in the amount of radioactive isotope (i.e. the number of radioactive nuclei) in a sample is shown in the following half-life curve.



Let N_0 represent the original number of radioactive nuclei in a sample and N represent the number of the remaining radioactive nuclei after any given time interval Δt , then

$$\text{At time } \Delta t = 0 \text{ s} ; N = N_0$$

$$\text{At time } \Delta t = T_{1/2} ; N = \frac{1}{2} N_0$$

$$\text{At time } \Delta t = 2T_{1/2} ; N = \frac{1}{2} \times \frac{1}{2} N_0 = \left(\frac{1}{2}\right)^2 N_0$$

$$\text{At time } \Delta t = 3T_{1/2} ; N = \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} N_0 = \left(\frac{1}{2}\right)^3 N_0$$

The general relation for the remaining number of radioactive nuclei is given by

$$N = \left(\frac{1}{2}\right)^n N_0 \dots \dots \dots (1)$$

Where n is the number of half-lives and can be found as

$$n = \frac{\Delta t}{T_{1/2}} \dots \dots \dots (2)$$

Different materials have different half-lives which ranges from 10^{10} years to a fraction of second.

Radioisotopes

Two or more forms of a chemical element having the same number of protons but having different number of neutrons are called isotopes. While,

the isotopes that are unstable and emit radiation are called radioisotopes.

Some of the radioisotopes of elements exist naturally while others are prepared in laboratories by the bombardment of subatomic particles. Among 3000 known nuclides, only 257 are stable and the remaining are unstable.

For example, carbon has 15 isotopes from ${}^8\text{C}$ to ${}^{22}\text{C}$, of which ${}^{12}\text{C}$, ${}^{13}\text{C}$ and ${}^{14}\text{C}$, while the remaining isotopes are artificial. The most stable artificial radioisotope of carbon is ${}^{11}\text{C}$ with half-life of about 20 minutes. All the other artificial radioisotopes have half-lives under 20 seconds up to less than 200 milliseconds.

Uses of Radioisotopes:

The radioisotopes have the same chemical properties as the stable isotopes of the same element. This property makes it useful in a wide variety of applications. Some of their applications are discussed below.

Food Preservation: Gamma rays are used to kill bacteria, mould and insects in food even after it has been packaged. This technology of food irradiation improves the safety and extends the shelf life of food.

Sterilization: Gamma rays are used to sterilize hospital equipment by irradiation, especially plastic equipment that can be damaged if heated.

Agriculture: Carbon-14 releases beta radiation. When it is added to a fertilizer and then given to a plant. The absorption of the fertilizer and its movement to different parts of the plant can be determined by measuring radiation from different parts of the plant. Furthermore, higher yield varieties of seeds

have also been developed after mutation through radiation.

Medical Uses: Ionizing radiation is used in medical diagnostics and radiation therapy.

- **Medical diagnostics:** Different organs in our bodies absorb different elements. For example, thyroid takes up iodine, brain consumes quantities of glucose, etc. The medical professionals enter a right dose of radioisotope of the element and use specific imaging techniques to evaluate the activity of the organ. This enables them to detect the progression and stage of the disease.
- **Radiation therapy:** Radiation therapy is a type of treatment, in which a beam of high energy radiation is used to destroy selected tissues, such as cancerous tumor. For example, cobalt-60, which emits beta particles and high energy gamma rays, can be used to treat various cancers.

Radioactive Dating: Radioactive dating (also called radiometric dating) is a technique used to determine the age of rocks and minerals. It compares the ratio of the observed amount of radioisotope and its decay products in the sample, using known decay rates.

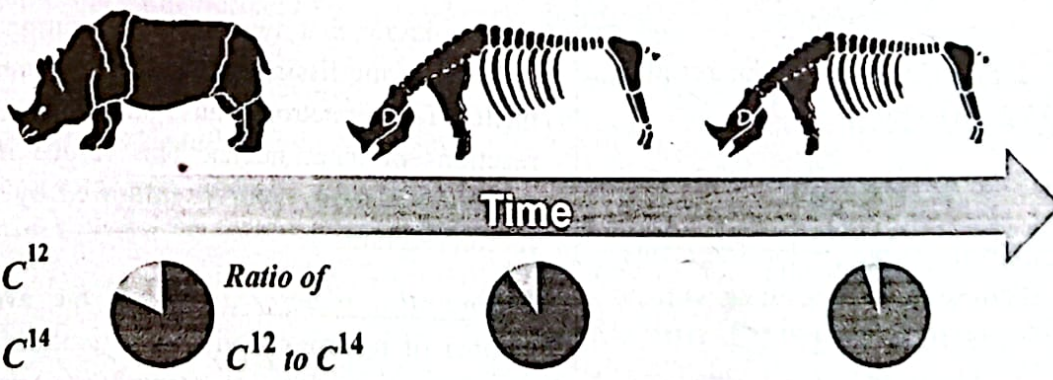
One example of radioactive dating is carbon dating. Carbon dating can be used on anything that was once alive, i.e. plants or animals. It compares the three isotopes of carbon, i.e. ^{12}C , ^{13}C and ^{14}C present in the body.

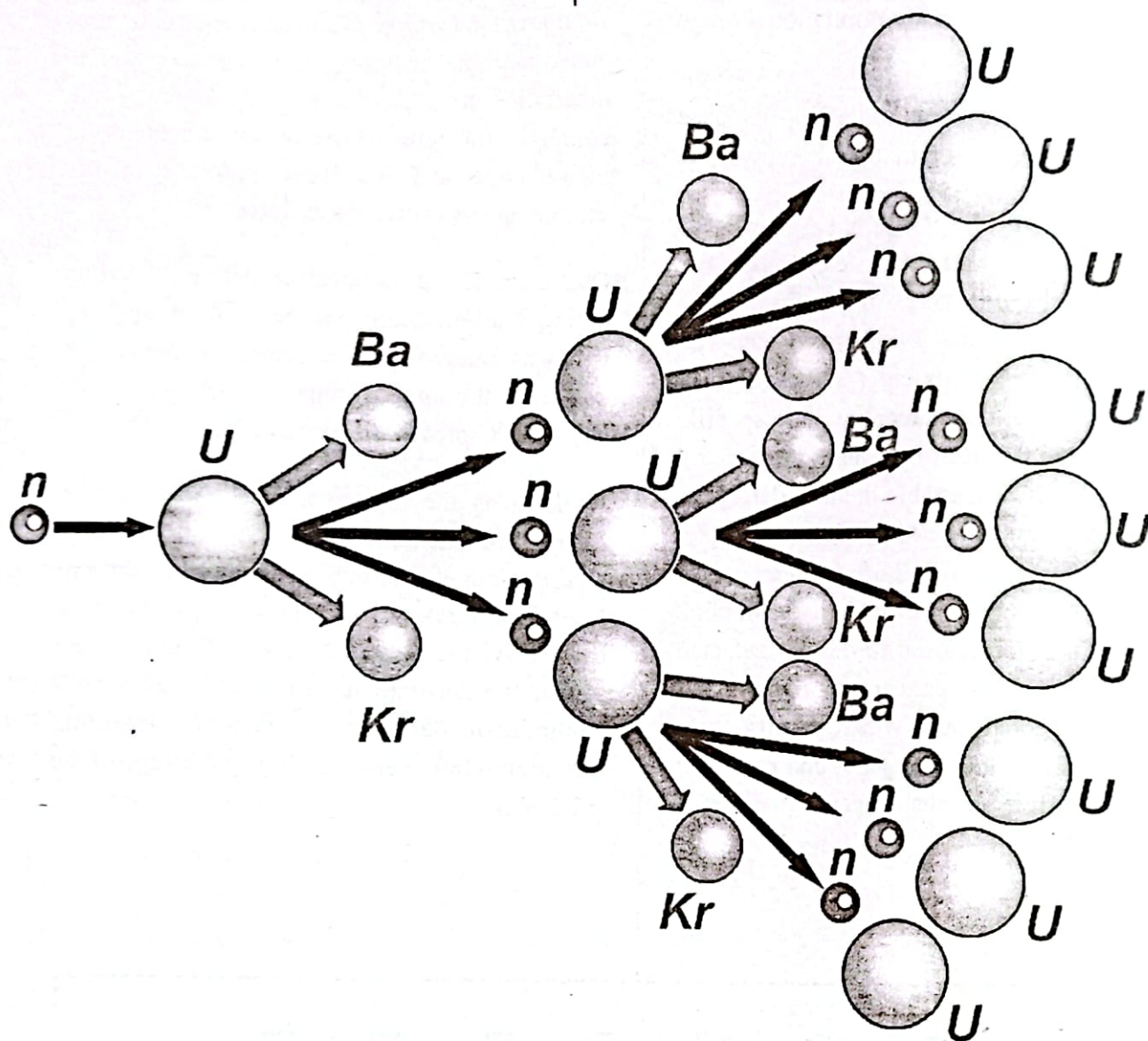
As long as the organism is alive, it absorbs carbon from the atmosphere and food, including a certain amount of natural radioactive carbon-14. When the organism dies, it stops absorbing carbon. As the lighter isotopes ^{12}C and ^{13}C are stable, the accumulated radioactive carbon-14 continues to decay to nitrogen-14. Measuring the amount left over gives an estimate of the age of the specimen.



C O N C E P T

CARBON DATING

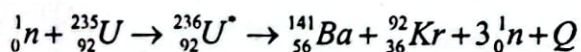




Nuclear Fission

The process of splitting of a nucleus into intermediate size nuclei accompanied with the release a large amount of energy is called fission.

A typical nuclear reaction for the fission reaction of uranium-235 is given by



Where Ba and Kr are called fission fragments. Two or three neutrons are emitted along with the release of nuclear reaction energy 'Q'.

The energy released in the fission reaction is very much larger than the energy released in

chemical reactions. It is estimated that the fission reaction of 1 kg of uranium releases as much energy as 3000 tons of coal.

Fission Chain Reaction:

As we know that two or three neutrons are released in the fission reaction of one uranium nuclei. These neutrons cause additional fission reactions in other nuclei. This results in the emission of more neutrons followed by more fission reactions.

Uncontrolled chain reaction: If the average number of neutrons available to produce new fission reactions is greater than 1 per reaction, then the number of fissions grows with time. This results in the production of a huge amount

of energy in very short time. This occurs in the explosion of atomic bomb.

Controlled chain reaction: If some of the released electrons are prevented from interacting with the uranium-235 atoms, then the chain reaction is called controlled chain reaction. This is achieved by using materials that absorb neutrons such as graphite. Controlled chain reaction occurs in nuclear power plants to produce useful energy.

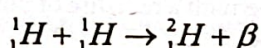
Nuclear Fusion

When two light nuclei combine to form a heavy nucleus, the process is called nuclear fusion.

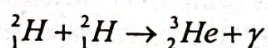
The energy released by fusion reaction is much greater than the energy released by fission reaction. This enormous amount of energy is due to the fact that the mass of the newly formed nucleus is smaller than the mass of the nuclei that formed it. The loss in mass appears in the form of energy.

Proton-Proton Cycle: This process occurs only in the sun and stars because the energy required to initiate and sustain it is possible only in the solar and stellar environments.

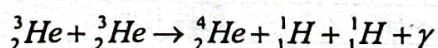
The proton cycle consists of the following nuclear reactions.



The deuterium produced in the above reaction combines with another deuterium as



Finally, the helium-3 produced in the above reaction combines with another helium-3 to form helium-4 with the release of two protons as



Background Radiation

The ionizing radiation that originates from natural sources such as radioactive materials in the soil and atmosphere, and the radiation from outer space are called background radiation. All living things are exposed to such radiation. The three main sources of background radiation are:

Cosmic radiation: The radiation from space is termed as cosmic radiation. The dose from cosmic radiation is different in different parts of the world due to differences in elevation and because of the earth's magnetic field.

Terrestrial radiation: The radiation from the radioactive materials in the soil, water, vegetation, and air are termed as terrestrial radiation. The dose from terrestrial sources also varies in different parts of the world.

Internal radiation: The radiation from the radioisotopes inside us are termed as internal radiation. For example, all people have radioactive potassium-40, carbon-14, lead-210 and other radioisotopes inside their bodies from birth.

Hazards from Radioactive Materials:

Nuclear radiation can alter the structure of molecules within a living cell which can cause the death of the cell and even of the organism itself.

Damage by irradiation: It is the damage of the cells of a person by the radiation directly.

Damage by contamination: It is the damage of or the cells of a person by the radiation emitted by the radioactive materials inside the body.

Radiation Sickness: Depending on the dose received by a person, the effects of radiation on humans can be grouped into two categories.

- Short-term effects:** The short-term effects (or acute effects) of radiation on humans are those that appear within minutes, days, or weeks. Depending on the severity of the dose, a person with short-term effects can suffer from nausea, vomiting, diarrhea, and loss of hair.
- Long-term effects:** Long-term effects (or latent effects) of radiation are those that may appear years, decades, or even generations later. A person with long-term effects can suffer from hair loss, eye cataracts, and various kinds of cancer. The genetic defects caused by the mutation of genes through radiation may be passed from one generation to the next.

Safety Measures: The following precautions must be taken to avoid exposure to ionizing radiation.

- Minimizing the exposure time.
- Maximizing the distance from the radiation source.
- Shielding from the radiation source. For this purpose, lab coats, shoes and safety glasses must be worn where the radioactive materials are handled.
- A radiation detector must be installed in the lab.
- International symbol of radiation must be posted in the lab.



International (trefoil) symbol of radiation

EXERCISE

Multiple Choice Questions

- What is the number of neutrons in the plutonium $^{242}_{92}\text{Pu}$?

A	92	B	142
	150	D	242
- Which one or more of the three decay process (α , β or γ) results in a new element?

A	Only α	B	Only β
C	Only γ		α and β
- What type of nuclear decay leaves the number of protons and neutrons unchanged?

A	Alpha decay	B	Beta decay
	Gamma decay	D	Both A & B
- What type of nuclear decay most often produces the greatest mass and charge loss?

	Alpha decay	B	Beta decay
C	Gamma decay	D	Both B & C
- $^{214}_{84}\text{Po}$ undergoes alpha decay to produce a daughter nucleus that itself undergoes beta decay. Which one of the following nuclei is the one that ultimately results?

A	$^{211}_{82}\text{Pb}$	B	$^{215}_{80}\text{Hg}$
C	$^{211}_{81}\text{Tl}$		$^{212}_{83}\text{Bi}$
- Radium-226 decays by emitting an alpha particle. What is the daughter nucleus?

A	Rd		Rn
C	Bi	D	Pb
- ^{39}Ar is an isotope with a half-life of 269 yr. It will reduce to half in

A	134.5 min	B	134.5 years
C	269 min		269 years
- A sample starts with 1000 radioactive atoms. How many half lives have elapsed when 750 atoms have decayed?

A	0.25	B	1.5
	2.0	D	2.5
- Origin of energy from the sun and stars is

A	Fission		Fusion
C	Carbon dating	D	radioactivity

Conceptual Questions

1. The atomic number of one particular isotope is equal to its mass number. Which isotope is it?

Ans. Hydrogen has three isotopes, i.e. protium (${}^1_1\text{H}$), deuterium (${}^2_1\text{H}$) and tritium (${}^3_1\text{H}$). The protium has only one proton in the nucleus. Therefore, its atomic number is $Z=1$ and mass number is $A=1$.

2. Which is more likely to expose, a film kept in a cardboard box, α -particles or β -particles? Explain.

Ans. As the radiation passes through a medium, it loses energy during the ionization process. Smaller the ionization ability of a radiation, greater will be its penetration ability. Since the ionization ability of β -particles is less than that of α -particles, therefore, β -particles can easily penetrate and expose the film.

3. Is it possible for a form of heavy hydrogen to decay by emitting an alpha particle? explain.

Ans. An α -particle is a doubly ionized helium nucleus that consists of two protons and two neutrons. Since a heavy hydrogen (deuterium) has only one proton and one neutron, so it is not possible for a heavy hydrogen to emit an alpha particle.

4. Different isotopes of a given element have different masses, but they have the same chemical properties. Explain why chemical properties are unaffected by a change of isotope?

Ans. Different isotopes of a given element have different number of neutrons and same number of protons. The number of electrons in a neutral atom is equal to the number of protons. Due to the same number of protons, each isotope has the same number of electrons. It means that all the isotopes of a given element have same electronic configuration, particularly valence electrons that determine the chemical properties of an atom. Thus, different isotopes of a given element have the same chemical properties.

5. What fraction of a radioactive sample has decayed after two half-lives have elapsed?

Ans.

Let N_0 = Original number of radioactive atoms
 N = Number of un-decayed atoms
 and N' = Number of decayed atoms

$$\text{then } N' = N_0 - N \dots \dots \dots (1)$$

As we know that

$$N = \left(\frac{1}{2}\right)^n N_0 \dots \dots \dots (2)$$

Since two half-lives have been elapsed, so $n = 2$

$$(2) \Rightarrow N = \left(\frac{1}{2}\right)^2 N_0 = \frac{1}{4} N_0 \dots \dots \dots (3)$$

Put equ. (3) in (1)

$$\begin{aligned} (1) \Rightarrow N' &= N_0 - \frac{1}{4} N_0 \\ &= \frac{4N_0 - N_0}{4} \\ N' &= \frac{3}{4} N_0 \end{aligned}$$

Hence three-fourth of the radioactive sample has decayed after two half-lives.

6. Can carbon-14 dating give the age of fossil dinosaur skeletons? Explain.

Ans. Carbon-14 dating can be used to estimate of the age of biological tissues as old as 50 to 60

Numerical Questions

How many neutrons are contained in a gold nucleus $^{197}_{79}\text{Au}$?

Given data :

Mass number 'A' = 197

Atomic number 'Z' = 79

Required :

Number of neutrons 'N' = ?

Solution :

As we know that

$$N = A - Z$$

(Put the values)

$$N = 197 - 79$$

$$N = 118$$

2. $^{220}_{86}\text{Rn}$ decays via alpha decay. Identify the daughter nuclide.

Given data :

Parent nucleus ' ^A_ZRn ' = $^{220}_{86}\text{Rn}$

Mass number 'A' = 220

Atomic number 'Z' = 86

Required :

Daughter nuclide 'Y' = ?

Solution :

As we know that

$$^A_Z X = ^{A-4}_{Z-2} Y + \alpha + Q \dots \dots \dots (1)$$

(Put the values)

$$(1) \Rightarrow ^{220}_{86}\text{Rn} \rightarrow ^{220-4}_{86-2}\text{Y} + \alpha + Q$$

$$^{220}_{86}\text{Rn} \rightarrow \boxed{^{216}_{84}\text{Po}} + \alpha + Q$$

So the daughter nuclide is polonium $^{216}_{84}\text{Po}$.

3. Write the nuclear equations for the beta decay of $^{210}_{82}\text{Pb}$ and $^{234}_{90}\text{Th}$.

Given data :

Parent nucleus " X_1 " = $^{210}_{82}\text{Pb}$

Parent nucleus " X_2 " = $^{234}_{90}\text{Th}$

Required :

a) $^{210}_{82}\text{Pb} \rightarrow ?$

b) $^{234}_{90}\text{Th} \rightarrow ?$

Solution :

As we know that

$$^A_Z X = ^A_{Z+1} Y + \beta + Q \dots \dots \dots (1)$$

a)

$$(1) \Rightarrow ^{210}_{82}\text{Pb} \rightarrow ^{210}_{82+1}\text{Y} + \beta + Q$$

$$\Rightarrow ^{210}_{82}\text{Pb} \rightarrow ^{210}_{83}\text{Bi} + \beta + Q$$

b)

$$(1) \Rightarrow ^{234}_{90}\text{Th} \rightarrow ^{234}_{90+1}\text{Y} + \beta + Q$$

$$\Rightarrow ^{234}_{90}\text{Th} \rightarrow ^{234}_{91}\text{Pa} + \beta + Q$$

4. Iodine-131 is an important radioisotope for medical diagnostic and treatment procedures. The half-life of ^{131}I is 8.02 days. Out of 100 g of the sample how much will be left after 24 days?

Given data :

Half life ' $T_{1/2}$ ' = 8.02 days

Total time elapsed ' Δt ' = 24 days

Total amount ' N_0 ' = 100g

Required :

Amount left 'N' = ?

Solution :

As we know that

$$N = \left(\frac{1}{2}\right)^n \dots \dots \dots (1)$$

$$\text{Where } n = \frac{\Delta t}{T_{1/2}} = \frac{24 \text{ days}}{8.02 \text{ days}}$$

thousand years, however, it is most accurate for younger samples. Since the age of dinosaurs, known as *Mesozoic Era*, is from about 245 million years ago to 66 million years ago. Therefore, it is not possible to determine the age of dinosaurs using carbon-14 dating.



7. *Some food is treated with gamma radiation to kill bacteria. Why is there not a concern that people who eat such food might be consuming food containing gamma radiation?*

Ans. Food is treated with gamma radiation to kill bacteria before preservation. This technique is used to extend the shelf life of the food and make it safe. The energy of the ionizing radiation should be sufficient to create positive and negative charges that harm the rapidly growth of bacteria. However, the energy levels of the gamma rays are too low to prevent the treated food from becoming radioactive.



8. *Radioactive α -emitter are relatively harmless outside the body but can be dangerous if ingested or inhaled. Explain.*

Ans. Alpha particles have the lowest penetrating ability. Due to which they can hardly penetrate the outer layer of the skin. So, exposure to radiation from a radioactive α -emitter outside the body is not a major concern. But, due to the highest ionizing ability of α -particles, it is very dangerous if radioactive α -emitters are ingested or inhaled. Because the ionizations can cause severe damage to cells and DNA.



9. *If nuclear radiation is harmful, how it can be used for treatment of diseases?*

Ans. Nuclear radiation is used for the treatment of various diseases, but it should be

kept in mind that it can be very harmful. For this purpose, only expert physicians are allowed to perform radiation therapy. The radiation therapy experts carefully measure the radiation dose. Also, the radiation is focused only on the affected tissues.



$$n = 2.99 \text{ days} = 3 \text{ days}$$

Put the values in equation (1)

$$N = \left(\frac{1}{2}\right)^3 \times 100 \text{ g}$$

$$N = \frac{1}{8} \times 100 \text{ g}$$

$$N = 12.5 \mu\text{g}$$

5. Phosphorus-32 is used in plant sciences for tracking a plant's uptake of fertilizer from the roots to the leaves. The half-life of ^{32}P is 15 days. Out of 800 μg of the activity given as fertilizer how much will be left after one month?

Given data :

$$\text{Half life } T_{1/2} = 15 \text{ days}$$

$$\text{Total time elapsed } \Delta t = 30 \text{ days}$$

$$\text{Total amount } N_0 = 800 \mu\text{g}$$

Required :

$$\text{Amount left } N = ?$$

Solution :

As we know that

$$N = \left(\frac{1}{2}\right)^n \dots\dots\dots(1)$$

$$\text{Where } n = \frac{\Delta t}{T_{1/2}} = \frac{30 \text{ days}}{15 \text{ days}}$$

$$n = 2 \text{ days}$$

Put the values in equation (1)

$$N = \left(\frac{1}{2}\right)^2 \times 800 \mu\text{g}$$

$$N = \frac{1}{4} \times 800 \mu\text{g}$$

$$N = 200 \mu\text{g}$$

6. ^{12}C to ^{14}C ratio in an animal fossil is found to be one fourth of the ratio in the bone of living animal. The half-life of ^{14}C is 5730 years, how old is the fossil?

Given data :

$$\text{Half life } T_{1/2} = 5730 \text{ years}$$

$$\frac{^{12}\text{C}}{^{14}\text{C}} = \frac{1}{4}$$

$$\Rightarrow \text{Amount left } N = \frac{1}{4} N_0 \dots\dots\dots$$

Required :

$$\text{Total time elapsed } \Delta t = ?$$

Solution :

As we know that

$$n = \frac{\Delta t}{T_{1/2}}$$

$$\Rightarrow \Delta t = n T_{1/2} \dots\dots\dots(2)$$

We also know that

$$N = \left(\frac{1}{2}\right)^n N_0 \dots\dots\dots(3)$$

Comparing equations (1) and (3), we get

$$\left(\frac{1}{2}\right)^n N_0 = \frac{1}{4} N_0$$

$$\left(\frac{1}{2}\right)^n = \left(\frac{1}{2}\right)^2$$

Equating powers on both sides, we get

$$n = 2$$

put the values in equ. (2)

$$(1) \Rightarrow \Delta t = 2 \times 5730$$

$$\Delta t = 11460 \text{ years}$$





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FORWARD

It is fortunate that I am inspired by my students to provide this physics guide. I often experience that my students want me to write my own notes when I emphasize on sentence structures of definitions, statements, etc., when I list the points on board during my lecture. For example, a capacitor can be defined as 'it is a device that is used for storing electrical energy' because other devices such as batteries, inductors also store electrical energy. But the definition 'a device that stores electrical energy is called capacitor' may be wrong, because here all the devices that store electrical energy are termed as capacitors. In this guide I have tried my best on quality writing. However, there may be some typing mistakes, so I request that if you find any mistake, do not hesitate to contact me.

Kishwar Khan

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